Coal deposits of Poland, including discussion about the degree of peat consolidation during lignite formation

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Abstract:
The paper gives an overlook about the deposits of hard coal and lignites in Poland. The first part describes the three main Polish black coal basins: Upper Silesian, Lower Silesian, and Lublin Basin. In 2006 Poland had an output of hard coals about 95 million tons and was one of the top ten producers in the world. Part two of the paper is focussed on lignites in the areas of Adamów, Konin, Turów and especially Belchatów. Poland is the second largest lignite producer in Europe. In the last part a method of determination the consolidation coefficient of lignite seams in the Wielkopolska region is explained. It is based on the method of HAGER et al. (1981) and the scientific goal is to quantify lignite consolidation.

Introduction:
Coal is a sedimentary rock and was formed by geological processes over millions of years. The influence parameters are the development level of the flora, geotectonics, basin formation, palaogeography, and sedimentary conditions. The four types of coal (lignite, subbituminous, bituminous and anthracite) are described and differentiated by rank. The anthracite has the lowest water and highest energy content but is not available in Poland. The most part of coal resources were used for power generation. For example, in 2001 the output of the four areas, Adamów, Belchatów, Konin and Turów went to 99,31% (Zbigniew Kozłowski 2003) into the power plants in Poland. In 2005 approximately 91,4% of the current was generated by hard coal and lignite.
Hard Coal

The existing reserves of black coal in Poland are very large and there is a long-established coal-mining industry. There are three coalfields of black coal in the country, Upper Silesia, Lower Silesia and Lublin. They occur geographically from south west to south east, and it is geological basement from the internal parts of Variscan orogen to the Precambrian platform of Eastern Europe. These regions represent large basins with huge sediment filling and varying degrees of structural disturbance.

Fig. 1: Location map of the hard coal basins (Kotarba et al., 2002 modified by Volkmer).

Upper Silesian Basin

The in recent time most important coal basin is the Upper Silesian located around the town of Katowice in the North, Cracow (East) and the Czech border (South). The Upper Silesian Coal Basin covers an area of about 7,400 km² in southern Poland and in the Ostrava-Karvina region in the Czech Republic. The Polish part is about 5,800 km². It is the most important coal basin of Poland and also one of the largest in Europe. Up to 30% of the deposit is explored by recent mining operations. The reserve deposits cover 23% and the perspective areas cover about 27% of the whole area. At the moment over 80% of coal deposits in Poland occur in this area.
The Upper Silesian Coal basin was formed as a foredeep of the Moravo-Silesian fold zone. It is a deep molasses basin of different origin. The layers of Namurian age was deposited in a paralic environment and the upper part from late Namurian to Westphalian D is of continental origin. The coal-bearing formations were subjected to erosion and denudation after the Variscan uplift. In the southern part of the basin, the coals are overlain by Miocene interbedded clay and sand of marine origin, and in the northern part by Permian-Jurassic layers. In the central part the Pennsylvanian strata are covered only by Quaternary sediments. The basin comprises a thick sequence of Upper Carboniferous sediments, up to 8,500 m. The rocks of that sequence include four lithostratigraphic units - the Paralic Series, Upper Silesian Sandstone Series, Siltstone Series and Cracow Sandstone Series. They represent Namurian and Westphalian ages. The upper part contains 60 coal seams and the lower part of the sequence contains 250 coal seams. The thickness of the seams can be up to 6-7 m. The mining operations in this basin are complicated because of the large scale faulting and folding caused by the high tectonics. Igneous intrusions of the Permian, Triassic and Miocene age influenced the coal rank. The coal is primarily high volatile bituminous, with low ash and sulphur contents. The Upper Silesian coal is the major export commodity.

Lower Silesian Basin

This coalfield is much smaller than the Upper Silesian Coalfield and contains thinner seams. The coal seams cover an area of about 350 km². The Lower Silesian Coal Basin is characterised by a considerable thickness variability and small horizontal and vertical extension of the coal-bearing formations. The basin makes up a part of the Intra-Sudetic Synclinorium. It is one of the largest geological structures of the Sudetes and it forms the easternmost part of the intramontane basin system of the Bohemian Massif. The Upper Carboniferous coal-bearing strata consist of a continental molasses sequence deposited in a crustal destruction basin in the interior zone of the Variscan orogenic belt. The coal seams are highly tectonised. The Pennsylvanian coal measures of the Lower Silesian Coal Basin are grouped in two main lithostratigraphical units, the Wal´brzych and Żacler formation. This units are of Namurian and Westphalian age. This basin contains about 30 coal beds with a thickness exceeding 1 m. The Lower Silesian Coalfield has been an important supplier of coking coal but today the mining is closed. The reasons for this are the difficult geological mining conditions (the remaining reserves are very deep) and unprofitable exploitation results. The identified resources in the Lower Silesian Basin are small and amount to about 150 million tons, these are only 0.25% of the whole identified reserves in Poland.
**Lublin Coal Basin**

The Lublin Coalfield will be the most important supplier of black coal in the future, because it is in the early stage of exploration. It is a large area with enormous reserves, which recently were discovered. The basin is located in southeastern Poland, close to the Ukraine border, and it covers an area of about 9,100 km².

This basin is a pericratonic depression within the East-European Platform. The coal-bearing lithostratigraphic sequence of the Lublin Coal Basin is difficult. The lower part is of marine-paralic origin, the middle part is paralic, and the upper part are continental sediments.

In comparison with the Silesian Coalfields, the seams are moderate structurally disturbed. Lublin has bituminous coals with low ash and sulphur contents with different coking properties. The coal seams are represented by four lithostratigraphic units of Carboniferous age (Terebin, Deblin, Lublin and Magnuszew formations).

The one exploited deposit in the Lublin Coalfield occupies an area of 50 km² (0.5%) and the identified deposits to a depth of 1,000 m cover about 67% of the area. The economic reserves constitute a bit more than 14% of total Polish coal resources.

**Hard coal resources and output in Poland**

The Polish Geological Institute amounted the identified economic resources of coal deposits to 42,580 million tons in December 2004. The reserves of the exploited deposits constitute actually about 37.6% of all economic resources and amount to 16,040 million tons.

The output of coal amounted to nearly 96 million tons in 2004. There are 48 operating underground mines, 47 mines in the Upper Silesian and one in Lublin Coal Basin. In the last years the mines reached a level forecasted for the nearest future.

![Fig. 2: Hard coal resources and output in Poland 1989-2004 (from Polish Geological Institute).](image-url)
The Polish coal exports reaches up to 20% of the recovered tonnage. The most important customers are Germany (7.264 million tons), Austria (2.145 million tons) and Slovakia (1.291 million tons).

Poland is one of the Top Ten Hard Coal Producers of the world (8th position) with an output of approximately 95 million tons in 2006.

**Lignite**

Tertiary lignites form single beds, lentils or complexes of beds in sediments belonging to the periods from Palaeocene to Upper Miocene. The surface of lignite-bearing strata in the Polish Lowland amounts to almost 100,000 km². The deposits occur mainly in the western, southern and central parts of the country. In 2004 the resources of lignite amount to 13,635 million tons, including 3,013 million tons of briquettable lignite, 1,875 million tons of lignite for low temperature carbonisation, and 0.8 million tons of bitumen rich lignite. The output amounted about 61 million tons, the Turów deposit close to the German border accounting for 17.7% and the Belchatów deposit in central Poland for 57.6%. The output decreased from 1989 (about 72 million tons) to the present (in 2006, 60.5 million tons).

*Fig. 3: Lignite resources and output in Poland 1989-2004 (from Polish Geological Institute).*
The coal production is mainly located in four areas: Adamów, Belchatów, Konin, and Turów, producing totally about 60 million tons a year (2003). The four open cast operations are situated on 2.1 billion tons deposits. Extracted lignite represents a fuel for power plants with a total capacity of 8833 MW, which generate approximately 35% of the electric energy in Poland. Seam thickness ranges from 5 m to over 70 m. The thicker seam has low ash and sulphur contents so they are mined for power generation. Almost the whole lignite output was consumed by power stations, and only 27.7 thousand tons were exported in 2004.

The Adamów Mine has a capacity of 4.2-5.2 million tons a year. They are mined from open pits of Adamów, Kozmin and Władysławów.

The Belchatów Mine has a capacity of 38.5 million tons a year. The two open pits in Belchatów and Szczerców will be closed in 2017, and 2031.

The Konin Mine has a capacity of 15 million tons a year. For example, there are open casts in Józwin, Drzewce and Lubstów.

The Turów Mine has a capacity of 15 million tons a year. This mine is expected to operate after modernization of its equipment complex until the year 2045. At this time the available deposits will be exhausted.
Table 1: The lignite production in 2001 (after Kozłowski, 2003).

<table>
<thead>
<tr>
<th>Concept</th>
<th>Unit</th>
<th>Adamów</th>
<th>Belchatów</th>
<th>Konin</th>
<th>Turów</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal production</td>
<td>Million Mg</td>
<td>4,319</td>
<td>34,664</td>
<td>11,381</td>
<td>9,117</td>
<td>59,541</td>
</tr>
<tr>
<td>Sales of coal to power plants</td>
<td>Million Mg</td>
<td>4,310</td>
<td>34,578</td>
<td>11,191</td>
<td>9,052</td>
<td>59,131</td>
</tr>
<tr>
<td>Sales of coal to power plants</td>
<td>Percent</td>
<td>99.79</td>
<td>99.075</td>
<td>98.34</td>
<td>99.29</td>
<td>99.31</td>
</tr>
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</table>

The following table describes the generation of electric energy by Polish power plants in the recent decade. Hard coal had a share of 56.9% and lignites 34.6% of total generation of electric energy in 2001.

Table 2: Generation of electric energy by Polish power plants from 1992 to 2001 (after Kozłowski, 2003).

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</thead>
<tbody>
<tr>
<td>Total generation of electric energy, out of which:</td>
<td>TWh</td>
<td>132.7</td>
<td>133.9</td>
<td>135.3</td>
<td>139.0</td>
<td>142.7</td>
<td>142.8</td>
<td>142.8</td>
<td>142.1</td>
<td>145.2</td>
</tr>
<tr>
<td>Utility thermal-power plants</td>
<td>TWh</td>
<td>120.4</td>
<td>121.1</td>
<td>122.7</td>
<td>126.5</td>
<td>130.5</td>
<td>131.0</td>
<td>130.9</td>
<td>130.6</td>
<td>133.8</td>
</tr>
<tr>
<td>Hard coal—fuelled</td>
<td>TWh</td>
<td>68.8</td>
<td>68.8</td>
<td>71.4</td>
<td>75.8</td>
<td>79.7</td>
<td>80.2</td>
<td>79.2</td>
<td>79.8</td>
<td>84.2</td>
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<tr>
<td>Lignite—fuelled</td>
<td>TWh</td>
<td>51.6</td>
<td>52.4</td>
<td>51.3</td>
<td>50.7</td>
<td>50.8</td>
<td>50.8</td>
<td>51.8</td>
<td>50.7</td>
<td>49.7</td>
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Electric energy generation from lignite against:

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>38.9</th>
<th>39.1</th>
<th>37.9</th>
<th>36.5</th>
<th>35.6</th>
<th>36.5</th>
<th>35.6</th>
<th>36.2</th>
<th>35.7</th>
<th>34.3</th>
<th>34.6</th>
</tr>
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<tr>
<td>Total generation</td>
<td>%</td>
<td>42.9</td>
<td>43.2</td>
<td>41.8</td>
<td>40.1</td>
<td>38.9</td>
<td>38.8</td>
<td>39.6</td>
<td>38.8</td>
<td>37.1</td>
<td>37.8</td>
<td></td>
</tr>
<tr>
<td>Generation of utility thermal-power plants</td>
<td>%</td>
<td>42.9</td>
<td>43.2</td>
<td>41.8</td>
<td>40.1</td>
<td>38.9</td>
<td>38.8</td>
<td>39.6</td>
<td>38.8</td>
<td>37.1</td>
<td>37.8</td>
<td></td>
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</tbody>
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The reserves of the four lignite mines will be exhausted between 2017 till 2045. But in northerly and westerly directions from Legnica the most abundant lignite deposits are located for the future. They contain 3.8 billion tons of lignite.
Belchatów

The brown coal area of Belchatów is located in central Poland. The Miocene coal appears in a series of tectonic grabens with a total length of more than 40 km and width of 1.5 to 2.0 km. The Mesozoic basement is covered by Miocene and Quaternary sediments. The Belchatów lignite deposit can be subdivided into four coal-bearing parts: underlying coal complex, coal complex, clay and coal complex and clay and sandstone complex. The coal complex with main seam and the seams B and C has the highest economic importance. Typical for the Belchatów brown coal deposit is the presence of tuffaceous intercalations (tonsteins). These are important correlative and stratigraphic horizons. Coal occurs at the depths from a few meters to 250 m, and its thickness ranges from 60 to 200 m. The coal was deposited in a freshwater environment on a tectonically active area. Fossil peat mires developed along rivers, often filling oxbow lakes in a warm to temperate climate.

![Fig. 5: Schematic stratigraphy of the coal section of the Belchatów deposit (after Ciuk, 1970).](image)

![Fig. 6: Geologic section of the Belchatów deposit (after Ciuk, 1970).](image)
A Calculation Method of the consolidation coefficient of lignite seams

In general, the consolidation coefficient is described as the original thickness divided by the present-day thickness of a deposit. Referring to lignite seam the consolidation coefficient is defined as the ratio between the peat bog thickness before burial and the present thickness of the resulting lignite seam.

The method was used on the Wielkopolska region (central Poland). Miocene lignites are exploited there in open-cast mines in the vicinity of Konin and Turek. The largest lignite deposits occur in four grabens (Adamów, Lubstów, Kleczew and Piaski) that were active in the Palaeogene and/or Neogene. They belong to two seam horizons, the first Middle-Polish Lignite Seam and the second Lusatian Lignite Seam. The last one is only located in the Lubstów Graben.

Fig. 7: Location of the Wielkopolska region (a). The investigated coal fields in Wielkopolska region (b) (after Widera et al., 2007 modified by Volkmer).

In the past some studies of the consolidation coefficient of lignite seams were realized, for example by WAGENBRETH, O. and BELLMANN, H.-J. (1983).

The here presented method is conceptually close to the method after HAGER et al. (1981). Investigations of lignite seams in open-cast mines, in combination with the results obtained from studies of modern peat-forming environments were taken into consideration. The watertable fluctuations and decomposition of organic matter during peat consolidation were very
important for the study.
The data of boreholes allow the calculation of the consolidation coefficient, but only under three conditions:

- Postsedimentary erosion of the surface of the peat bog and the lignite seam is absent. Profiles of boreholes with clayey and silty deposits at the top of lignite seams can be used, but profiles where the lignite seams are overlain by sands, gravels or Pleistocene glaciogenic deposits should not be used as input data.
- Postsedimentary tectonic and/or glaciotectonic deformations are excluded.
- Mineral intercalations in the lignite seam are absent.

The later given equation is based on hypothetical boreholes data. The first borehole contains a thin lignite seam and the second one a thick lignite seam.

![Fig. 8: Scheme of the initial peat-bog architecture before consolidation (a). Scheme of the present-day lignite seam architecture (b) (after Widera et al., 2007).](image)

The following equation can be applied to both boreholes:

\[
C_c = \frac{(Z_{\text{max}} - B_2)}{(T_2 - B_2)}
\]

- consolidation coefficient
- \(Z_{\text{max}}\) - top level of the peat bog before burial
- \(B_2\) - present-day level of the thick lignite seam
- \(T_2\) - top level of the thick lignite seam

With the help of different equations \(Z_{\text{max}}\) can be calculated and so it can be used for the determination of \(C_c\). On this basis the consolidation coefficient of some lignite seams in the Wielkopolska region can be estimated. The \(C_c\) of the first Middle-Polish Lignite Seam may be considered to a range between 1.80 and 2.14.

This method is based on the analysis of boreholes with thick central and thin marginal lignite seams within one peat bog basin. Of course this way to calculate the consolidation coefficient has advantages and disadvantages, too. It is mathematically quite easy to estimate the original thickness of the peat bog and the effects of postdepositional tectonic displacements of the resulting lignite seam can be estimated. The disadvantage is that you need a lot of reliable results from a big number of boreholes (uncommonly accurate drilling documentation) and the obtained consolidation coefficient is only valid for the selected boreholes.
References


Verein der Kohlenimporteure e. V. (2006)

World Coal Institute (2007) Coal Facts:
http://www.worldcoal.org/

Polish Geological Institute:

Statistik der Kohlenwirtschaft e. V. (2006)
http://www.kohlenstatistik.de/download/Komplett_Kohlenwirtschaft.pdf