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INTRODUCTORY LECTURE

LOW-RANK COALS IN POLAND: PROSPECTION – MINING – PROGRESS

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A b s t r a c t . Low-rank coal resources occur in Poland commonly within Tertiary deposits. Miocene coal-bearing deposits are most substantial; resources related to them are located in the eight lignite-bearing regions with total quantity above 40 bill. Mg. Origin of major lignite deposits are tectonic and subrosional. Coal of the 4 economic seams belongs to the hypolignite group and is of rather good quality.
Lignite in Poland is exploited from more than two hundred years. Recently, four large mines operate in central Poland (Adamów, Bełchatów and Konin) and south-eastern Poland (Turów). They produce about 60 mil. Mg of lignite per year. Almost whole coal is used as energy resource for five mouth-mine power plants, producing ca. 52 mil. MWh annually, and covering ca. 40% of Poland recent requirements. This energy is the cheapest one in Poland. Small amounts of lignite cover local requirements, and are used for production of valuable fertilisers. Also by-products: ceramic and kaolin clays, bentonite, quartz sand and aggregate, and bog-lime are selectively exploited. The Legnica region is regarded as the most probable new operating mining area in the future.
Complex technologies applied recently allow to substantially decrease environmental impact of mining, and the reclaimed areas are returned to agriculture and forestry. Final excavations are used as waste storage areas, and part of them is transformed into scenic lakes. Proper environmental protection and reclamation procedures are extremely important, because future of lignite mining development depends on its social acceptance.

K e y w o r d s : lignite resources, coal quality, power production, coal mining, by-products, perspectives, Tertiary, Poland.

INTRODUCTION

Low-rank coals occur in Poland within Mesozoic and Cainozoic sediments. Sub-bituminous coals and metalignites are known within the Lower Jurassic and Upper Cretaceous rocks, and hypolignites are common within the Tertiary deposits. Small deposits of the Mesozoic coals were exploited in the past in underground mines but their exploitation has been abandoned. Only Miocene low-rank coals, common in Western Poland, with large reserves and good geological/mining parameters, are mined today in several open cast mines. They are the most important energy resources in Poland.

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OCCURRENCE AND STRATIGRAPHIC POSITION

Numerous lignite deposits occur mostly in the Western and Central Poland (Fig. 1), and they are mostly located in the Polish Lowlands area where eight major regions of their concentration have been defined (Fig. 2, Table 1). Only few small deposits of lignite, with no economic significance, occur outside the Polish Lowlands; they are: Liassic deposits in the Cracow–Wieluń Upland and Neogene deposits in marginal part of the Carpathian Foredeep (Ciuk, Piwocki, 1990).

On the Polish Lowlands, seven coal seams have been distinguished within the Tertiary stratigraphic column. The two oldest ones, placed within Upper Palaeocene (the 7th Odra seam) and Middle Eocene (the 6th Tanowo seam), have no economical significance. They cover an area of 600 km^2 but they are placed too deeply. Coals of the 5th Czempin seam cover an area of 7700 km^2 but only locally they may be defined as economic. They are thicker (even up to 45 m) in few deposits only

Table 1

Lignite resources in Poland

Region	Number of deposits	Total reserves [mil. Mg]
Bełchatów	8	2440.4
Konin	58	1050.4
Legnica	13	14428.9
Łódź	6	773.9
North-western region	5	941.3
Radom	5	95.4
Western region	62	6122.3
Wielkopolska	21	14225.3
Deposits outside the regions	12	40.7
Total	190	40148.6

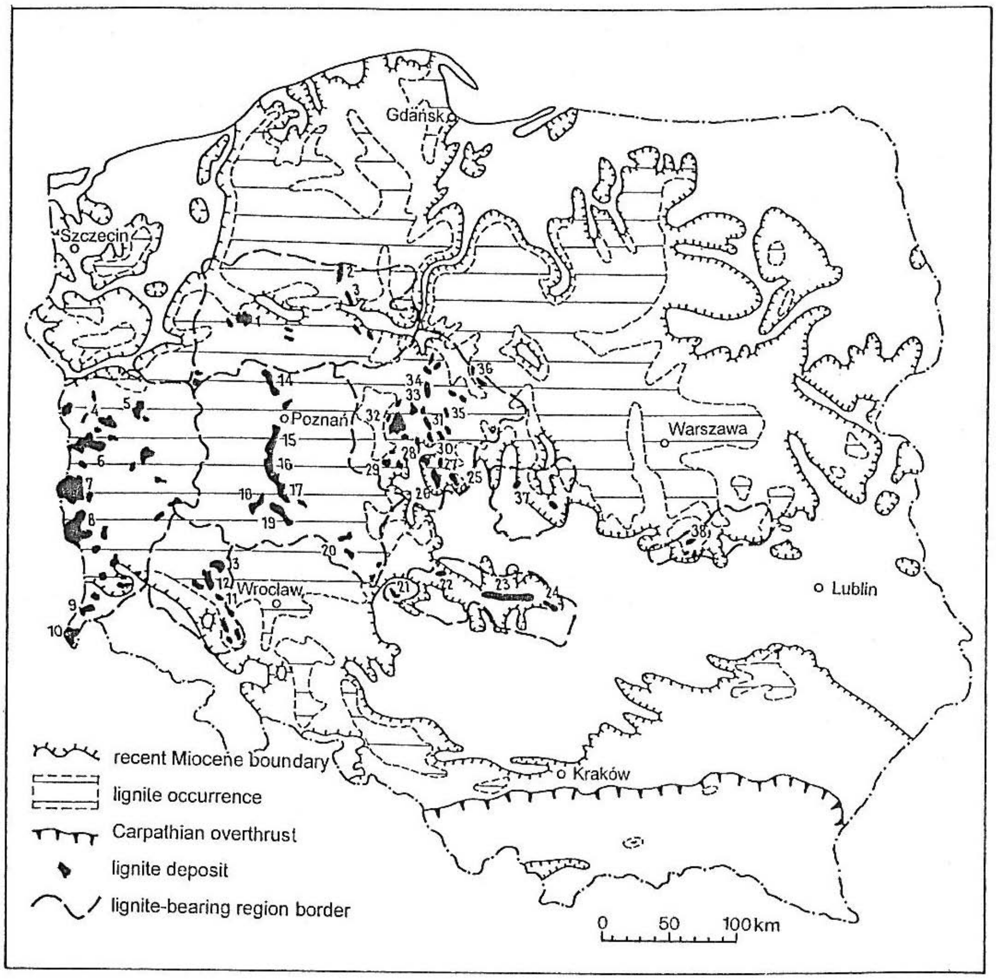

Fig. 1. Map of the lignite deposits in Poland

Major lignite deposits: *1* — Trzcianka, *2* — Więcbork, *3* — Nakło, *4* — Słubice-Rzepin, *5* — Sieniawa, *6* — Cybinka, *7* — Gubin, *8* — Babina-Mosty, *9* — Radomierzyce, *10* — Turów, *11* — Ruja, *12* — Legnica, *13* — Ścinawa, *14* — Szamotuły, *15* — Mosina, *16* — Czempin-Krzywiń, *17* — Gostyń, *18* — Góra, *19* — Poniec-Krobia, *20* — Sulmierzyce, *21* — Wieruszów, *22* — Złoczew, *23* — Bełchatów, *24* — Łęki Szlacheckie, *25* — Uniejów, *26* — Adamów, *27* — Koźmin, *28* — Władysławów, *29* — Piaski, *30* — Drzewce, *31* — Lubstów, *32* — Pątnów, *33* — Morzyczyn, *34* — Chełmce, *35* — Dęby-Izbica, *36* — Brzezie, *37* — Rogóźno, *38* — Głowaczów

Fig. 2. Coal-bearing regions in Poland (after Kasiński *et al.*, 1991)

Bituminous coal basins: *1* — Lower Silesian, *2* — Upper Silesian, *3* — Lublin; lignite-bearing regions: A — Western, B — North-western, C — Legnica, D — Wielkopolska, E — Konin, F — Łódź, G — Bełchatów, H — Radom

(Rogóźno, Łanięta, Bąkowo), and potentially may be mined together with younger Miocene seams.

Coal seams, developed within Lower and Middle Miocene deposits, are substantially important for economy of Poland. They spread over the area of ca. 70,000 km^2. They are an eastern continuation of the large Lower Lusatian Lignite Basin of East Germany.

The 4th Dąbrowa lignite seam (Fig. 3) occurs in the lower part of Lower Miocene and covers an area of ca. 7000 km^2 in south-west Poland (Piwocki, 1998). Its thickness reaches up to 30 m (5.8 m in average) inside the borders of lignite deposits. The 3rd Ścinawa seam occurs in the same part of Poland covering ca. 30,000 km^2. It is also economic in some deposits reaching up to 35 m in thickness within tectonic depressions. Two younger seams: the 2nd Lusatia seam and the 1st Mid-Polish seam, built the main coal-bearing horizon. The 2nd Lusatia seam occurs in the stratigraphic column at the border between Lower and Middle Miocene. It covers an area of ca. 61,000 km^2 (Piwocki, 1992), but is economically valuable only in western and south-western Poland. It is usually up to 40 m thick within stratified deposits, and up to 250 m thick within tectonic depressions (Bełchatów deposit within the Kleszczów Trough). The 1st Mid-Polish lignite seam covers ca. 70,000 km^2 (Piwocki, 1998). It is economically important particularly in the Middle Poland and its thickness reaches up to 20 m within stratified deposits.

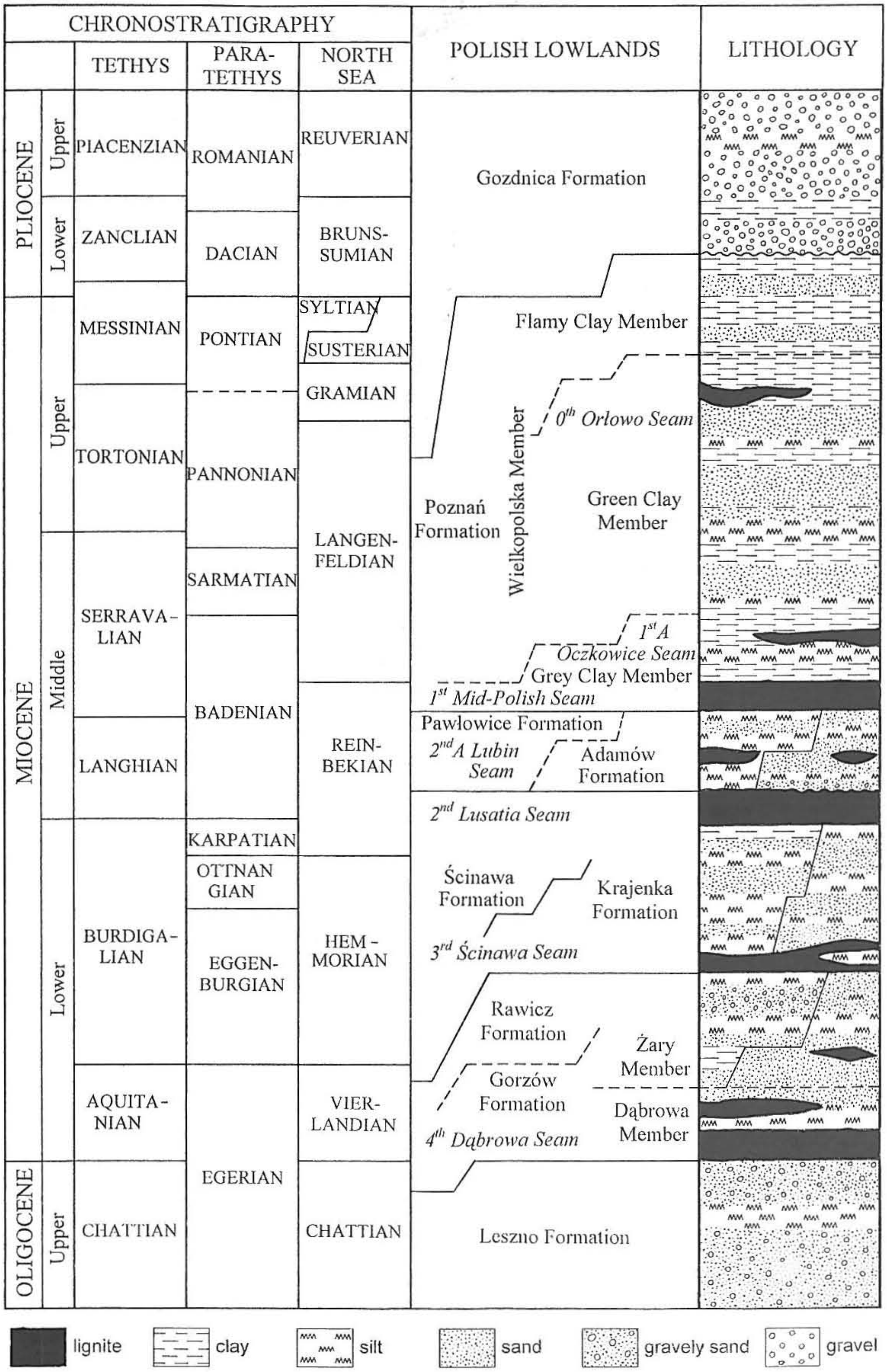

Fig. 3. Synthetic stratigraphic profile of the Tertiary lignite-bearing association (after Piwocki, 1992)

ORIGIN AND GEOLOGICAL SETTING OF MIOCENE LIGNITE DEPOSITS

Tertiary lignites of the Polish Lowlands developed in the peripheral part of the large Northwest European Tertiary Basin (Vinken, ed., 1988). Their origin is closely related to the basin evolution. Phytogenic material – lignite precursor – accumulated in favourable palaeogeographic, climatic, and geotectonic conditions, in brackish and continental facies. Lignite origin has been closely related to regional (epeirogenic) subsidence of large structural elements, and to local block subsidence, generating numerous tectonic troughs. In the western part of Poland, accumulation of phytogenic matter in brackish conditions was related to transgressive/regressive cycles. The thickest seams originated during transgressive stages. Extremely thick coal seams developed within tectonic depressions as a result of tectonic subsidence. Some thick coal seams originated also at the top of salt diapires, generated by halokinetic and subrosional processes.

Glacitectonic deformations, which removed fragments of coal seams located nearby Earth surface, played also a substantial role in origin of lignite deposits of the Polish Lowlands.

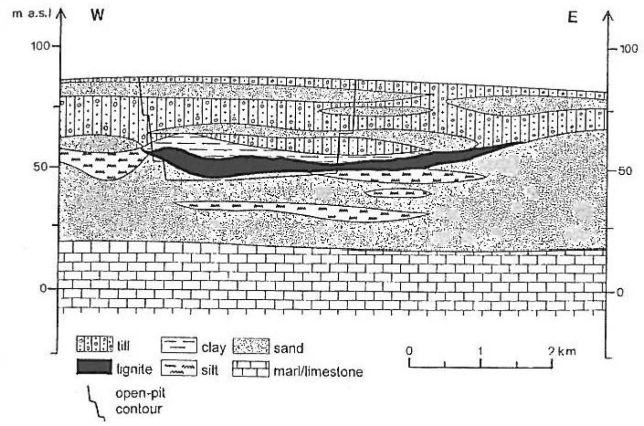

Fig. 4. Geological cross-section of the Pątnów III deposit (Kazimierz Północ open-pit) — an example of epeirogenic subsidence with autocyclic control of sedimentation

Table 2

Genetic groups of lignite deposits — characteristic features

Group	Type	Morphological form	Characteristic features
"Primary"	epeirogenic	stratiform	large area low thickness high stripping ratio
		lenticular	close area low thickness high stripping ratio
	tectonic	tectonic-trough sedimentary fill	medium area high thickness low stripping ratio
	subrosional	salt-karst	medium area medium thickness medium stripping ratio
		carbonate-karst	small area medium thickness low stripping ratio
"Secondary"	glaciotectonic	narrow folds and slices	close area high thickness low stripping ratio

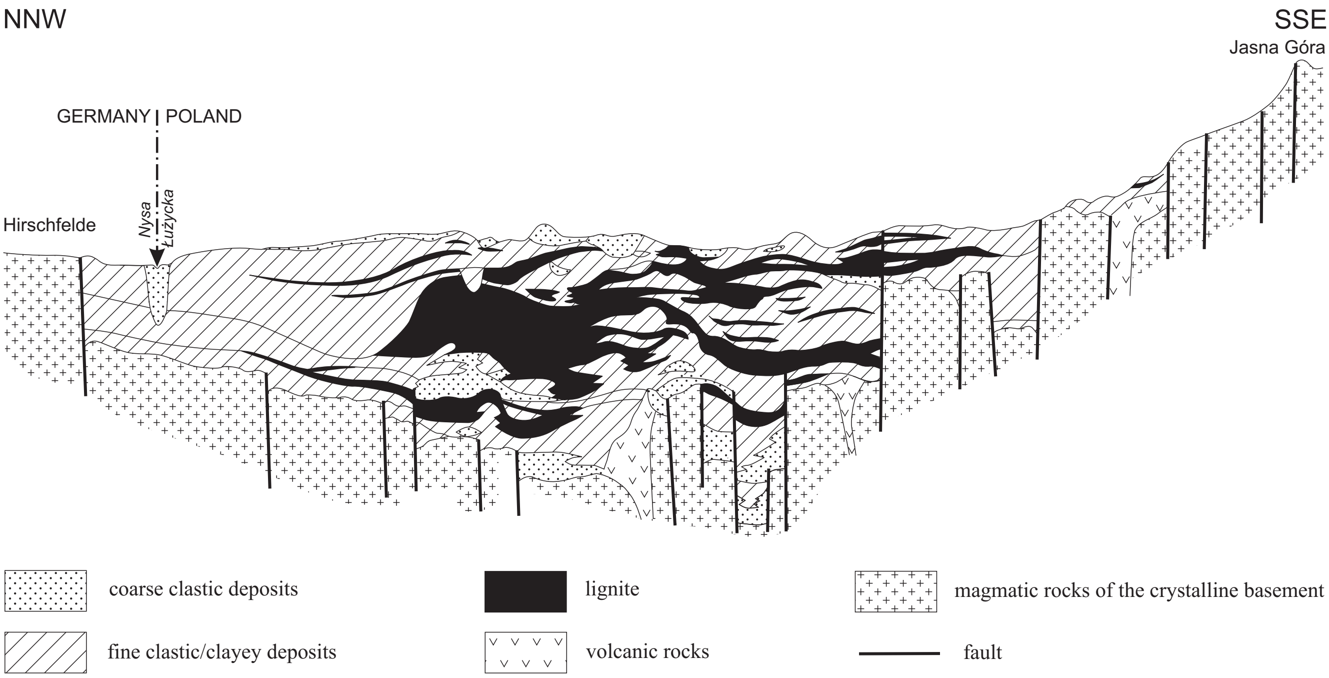

Fig. 5. Geological cross-section of the Turów deposit (after Kasiński, 2000) — an example of tectonic subsidence with allocyclic control of sedimentation

They were mostly related to the South-Polish Glaciation (Elsterian) and the Mid-Polish one (Saalian).

Two major genetic groups of lignite deposits may be distinguished in Poland. There are as follows:

"primary" deposits — lignite accumulation has been a result of synsedimentary processes:

— epeirogenic: subsidence with autocyclic control of sedimentation (Fig. 4),

— tectonic: subsidence with allocyclic control of sedimentation (Fig. 5),

— dissolution of underlying rocks (subrosion/karstification) (Fig. 6);

"secondary" deposits — lignite accumulation has been a result of post-sedimentary processes; of these, only one group has an economical significance, namely:

— glaciotectonic deposits (Fig. 7).

The individual defined groups are differentiated with their morphological form, extension, thickness, and geological/mining parameters (Table 2).

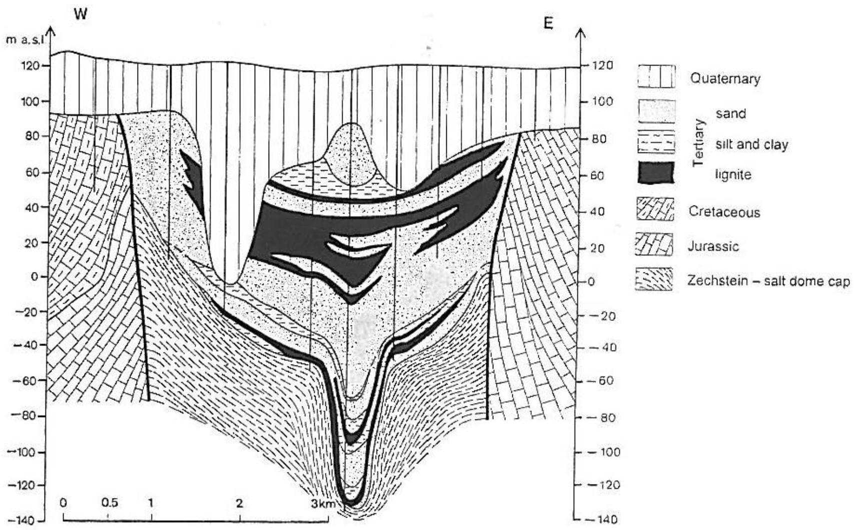

Fig. 6. Geological cross-section of the Rogóźno deposit — an example of subrosion (underground solution) of underlying salt rocks

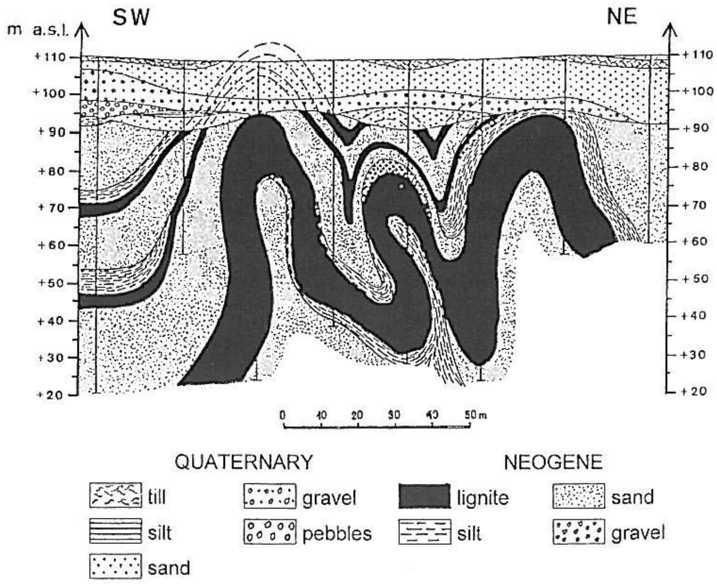

Fig. 7. Geological cross-section of the Sieniawa deposit (after Ciuk, 1968) — an example of glaciotectonic deposits

COAL QUALITY

Lignite exploited in Polish mines is of rather good quality; its basic average parameters are as follows:

heating value Q_i^r	8000–9300	MJ/Mg
ash content A^d	18–27	%
total sulphur content S_t^d	1.6	%
bitumen content B^d	4.4	%
tar content T_{sk}^d	11.5	%
alkali content $(Na_2O+K_2O)^d$	0.17	%
moisture W_r^t	53	%

Coal of the Wielkopolska Region is of the best quality (Table 3). It is characterised by high heating value, low ash content, and relatively low sulphur content. Coal of the Western Region is also very good but it contains a little more sulphur. Lignite from the Radom Region is the worst: it contains the least sulphur but it has low heating value and high ash content.

Within the economic coal seams (Table 4), the 2nd coal seam is of the best quality; its heating value is a little lower than in the 3rd and the 4th ones but sulphur content is much lower. The high ash content diminishes value of the 1st seam, and the high sulphur content – of the both older seams (particularly the 4th one).

However, distribution of coal parameters value inside one deposit is rather irregular, particularly in the case of tectonic basins.

Table 3

Average lignite parameters of the regions

Region	Coal parameters		
	Heating value Q_i^r [MJ/Mg]	Ash content A^d [%]	Total sulphur content S_t^d [%]
Bełchatów	8538	22.28	1.53
Konin	8139	25.16	1.26
Legnica	8536	22.09	1.94
Łódź	8970	23.89	2.70
North-western Region	7487	25.37	1.47
Radom	6792	34.50	0.48
Western Region	9416	17.55	1.37
Wielkopolska	9390	17.24	0.89

Table 4

Average lignite parameters of the seams

Parameter			Coal seam			
			1st	2nd	3rd	4th
Volatile matter	V^{daf}	[%]	56.12	53.49	54.28	56.08
Elementary carbon	C^{daf}	[%]	61.36	65.39	66.79	65.84
Elementary hydrogen	H^{daf}	[%]	4.97	4.82	4.65	5.20
Heating value	Q_i^r	[MJ/Mg]	7976	8989	9169	9613
Ash content	A^d	[%]	27.53	20.73	21.09	17.85
Total sulphur content	S_t^d	[%]	1.25	1.31	2.40	2.91
Tar output	T_{sk}^d	[%]	10.53	10.94	9.50	12.00
Bitumen content	B^d	[%]	4.47	4.45	4.00	5.00
Moisture	W_i^r	[%]	52.50	52.80	51.00	50.00

ECONOMIC RESOURCES AND THEIR DISTRIBUTION

Economic geological resources and reserves of Neogene lignite in Poland are of 14,050.7 mil. Mg (status at 1999-12-31), and reconnaissance resources are of 21,800.0 mil. Mg. Total economic geological resources of the operating mines are of 2145.0 mil. Mg and in this, the total proved resources are of 1951.7 mil. Mg. Lignite deposits are placed in Western Poland, and they are concentrated in the eight regions (*vide* Fig. 2).

Lignite resources in Poland are quite well known. The prospective areas of Neogene sediments of ca. 70,000 km^2, including the major lignite seams, have been explored in 40–75%, and the operating mines area — in ca. 90%.

Lignites of the 2nd and 1st coal seams create a base of geological lignite resources and reserves in Poland; lignite of the 2nd seam represents ca. 65% and lignite of the 1st seam — ca. 25% of the resources. Lignite resources extend over an area of ca. 5400 km^2. Out of this, explored deposits cover ca. 900 km^2, and with the reconnaissance work only — ca. 4500 km^2. Total area of exploited deposits is recently ca. 100 km^2. The most of the resources is located in the Legnica, Wielkopolska, and Western Poland regions (*vide* Table 1). Economic geological resources belong in ca. 35% to both the measured and indicated categories.

The whole volume of lignite is suitable for power production; part of it (13%) may be used for briquetting, and 21% for tar production in the semi-cooking process.

DEVELOPMENT OF MINING ACTIVITY

The first deposits of lignite inside the recent Poland area were discovered in 1640, after the great fires on lignite exposures near Zgorzelec, in the Western Lignite Region. Exploitation of lignite continues since 1740 when the first underground lignite mines started to work in that area. They were described for the first time also in 1740 in German (this area was part of German territory at that time), and defined as peat:

"Zu Herwigsdorf, bey Zittau findet man eine Art brennende Erde, so dem Turfe gleichet; zu Tauschritz aber, zwischen Zittau und Görlitz, wird jetzo wirklich der beßte Turf gegraben, dergleichen sich auch an anderen Orten geäußert hat" (*fide* Schneider, 1966). Before the end of the 19th Century, more than 100 small underground mines worked there. The first large-scale lignite open cast mine Hercules (today Turów) began to work there in 1905. In 1941, first lignite mine in the Konin Region (Central Poland) was opened.

After the World War II, lignite output increased systematically. Up to 1955, one forth of lignite production covered the national requirements and the rest was exported. During the following time, up to 1960, 35% of extracted lignite were used for Polish economy. The concept of using lignite in Polish power plants dramatically increased the exploitation during the 1960-ties. An extensive exploitation of the rich Turów lignite deposit, and some of the deposits located in the Konin Region, resulted in development of spreading open-pits supplying new large mouth-mine power plants: Turów in the Western Region, and Adamów and Pątnów in the Konin Region.

In 1977, Poland started to construct one of the largest open cast mine in the world. The lignite mine Bełchatów, in the Bełchatów Lignite Region, gave first tons of lignite in 1981. Presently, only four great lignite mines, located in three lignite regions, operate in Poland. They are: Adamów and Konin mines in the Konin Region, Bełchatów in the Bełchatów Region, and Turów in the Western Region. The last small underground Sieniawa lignite mine is recently being closed.

The active mines, based on large open-pits (9 open-pits in operation and 3 ones under construction), supply lignite to five mouth-mine power plants. Integrated systems: excavator-conveyer-dump machine, move lignite and overburden rocks from mines to power-plant storages and overburden dumps. Material is moved with large mobile excavators: bucket-wheel and continuous-bucket excavators with efficiency of 30–200 thou. cubic meters per day. Excavated material is transported with cross-pit walking conveyers. 1.8 m wide conveyer feeders move with speed reaching up to 6 km/h. Overburden rocks are transported with a little wider feeders (2.25 m wide) to the high-efficiency dump machines, storing it on external and/or internal dumps. High-yield well barriers secure proper dewatering of the open-pits.

Basic mining parameters in the operating mines are:

— linear overburden coefficient (geological) — 2.2–7.3; average 2.9;
— volume overburden coefficient (industrial) — 4.5–8.8; average 7.6.

Total lignite output in Poland increased many times since the end of the World War II, and in 1999 it was equal to 60.9 mil. Mg; it continues on more or less the same level during the last years (Fig. 8). From the viewpoint of lignite mining volume, Poland took in 1995 the fourth place in the world, after Germany, the states of the former Soviet Union, and USA. Lignite output in Poland was similar to that in Greece, Czech Republic, Turkey, and Australia.

Three mines cover ca. 92% of total exploited volume. They are: the Bełchatów mine – 35.5 mil. Mg, i.e. ca. 58%, the Konin mine — 11.8 mil. Mg, i.e. ca. 19%, and the Turów mine — 9.0 mil. Mg, i.e. ca. 15%.

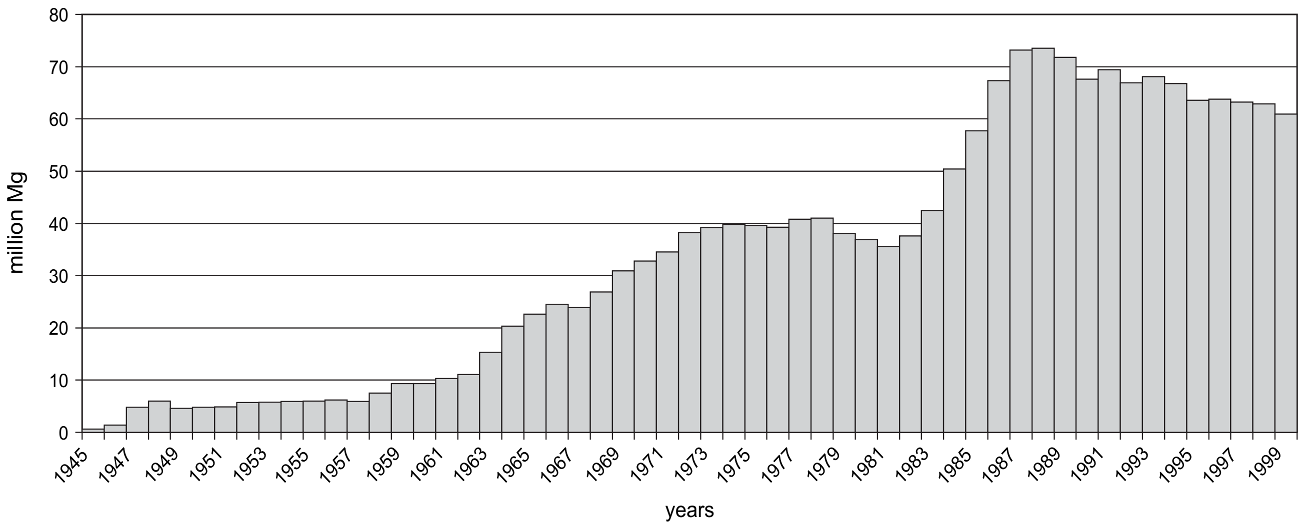

Fig. 8. Total lignite output in Poland since 1946

UTILISATION OF LIGNITE

In Poland, lignite is used mostly as fuel for electricity production in some large heat mouth-mine power plants, with total capacity of 8703 MW. It plays an important and stable role producing 51.8 mil. MWh and covering 39.6% of the whole power plants production. Lignite covers also 13.7% of primary energy requirements of Poland (Fig. 9).

Lignite resources of the operating mines will cover the existing power-plant requirements up to 2050. Lignite production will be relatively stable up to 2020 at the level of 60–65 mil. Mg per year, and during next several years, it will systematically decrease. Perspectives of further activity of the operating mines are satisfactory: 23 years for the Adamów mine, 40 years for the Bełchatów mine (69 years in case of satellite deposits exploitation), 40 years for the Konin mine, and 40 years for the Turów mine (52 years in case of exploitation of the Radomierzyce satellite deposit).

Lignite is also used at local scale for heating purposes. As lignite contains natural organic matter and high amount of microelements, some kinds of good quality ecological fertilisers are produced recently on the base of low-sulphur lignite in the Bełchatów, Konin, and Turów lignite mines. The fertilisers improve soil structure, first of all increasing its porosity, and maintain soil humidity. Therefore, lignite has a good chance to become an important ecological fertiliser which can guarantee the regeneration of devastated and degraded soils as well as the improvement of low-value soils.

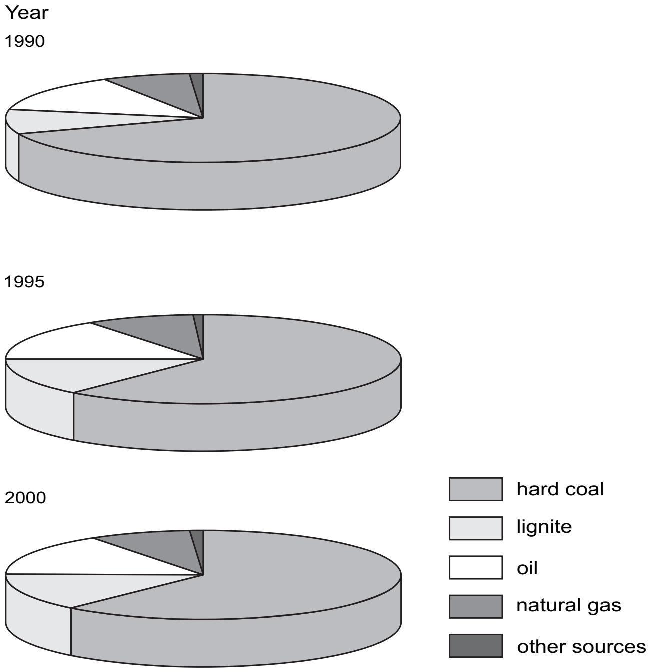

Fig. 9. Structure of primary energy use in Poland (after Bielikowski *et al.*, 1999)

BY-PRODUCTS FROM LIGNITE DEPOSITS

Problem of by-products was closely related to the lignite mining, since its starting in Poland area. It seemed to be extremely substantial during the time of large-scale lignite exploitation, in the open cast mines covering requirements of great power plants. Accompanying mineral resources occur usually within lignite deposits, within interbedding rocks (Wiśniewski, 1995; Ratajczak, 1996; Kasiński *et al.*, 2000). The updating technologies make possible selective mining of various materials. Effective costs of this activity are small, and economic, ecological, and social profits are substantial. Some kinds of clay (clay for brick production, kaolin clay, refractory clay, clay for cement production, clay for soil remediation, bentonite), and quartz aggregates and sands (natural aggregate for building and road construction, cellular concrete and lime-sand brick component, glass and foundry sand) occur commonly in major part of the deposits.

Clay raw materials are common within overburden and interbeddings of lignite. Upper Miocene/Pliocene ceramic clays are substantial overburden components in major part of the deposits. Before the World War II, they were mined in numerous small lignite deposits together with lignite, and used in the mouth-mine brickyards combusting lignite from the same deposit. Profit from mining of by-products may be economically important also today, and may decide on economical value of such kind of the deposits (Ratajczak, 1993).

Recently, ceramic clays from the Konin lignite-bearing region (the Konin and Adamów mines) are also used for bricks production (the brickyards Honoratka and Wielenin). Great amount of these clays is excavated in the Bełchatów lignite mine; part of them is used for construction of water-tight screens of communal litter dumps. Major part of clay is stored there as the "secondary deposit" on the internal dump surface. Miocene kaolin clays, useful for production of (1) fire-proof materials, (2) ceramic plates, porcellanite, and stoneware, (3) fill for paper, rubber, and plastic industry, and (4) complex agricultural fertilisers (intercalates), occur in great amount in the Turów deposit (Kaczarewski, Krzywobłocki, 1995), and also in the Bełchatów one (Wyrwicki, 1995a). Quaternary clayey-silty varvites, occurring within overburden rocks of the Bełchatów deposit, may be used for keramsite, and thin-wall construction. Special kind of this clay, free of sand, and including over 10% of $CaCO_3$, may be used as a glaze clay, very rare in Poland (Wyrwicki, 1995b).

Quartz sands and aggregates, Quaternary and Miocene in age, are common in overburden rocks in the all lignite deposits. They are exploited in all the lignite mines and used for mine construction, and partly sold to other users for road construction, filtration gravel, and anti-corrosion sand. Special kind of chert aggregate, with very good mechanic parameters, occur within the Bełchatów deposit. In the Bełchatów mine, ca. 100,000 m^3 of aggregate is exploited yearly.

Bog-lime of Miocene age occurs within the Bełchatów lignite deposit, and its resources are several millions cubic metres there. It is characterised by high content of $CaCO_3$ (80–90%), high chemical activity, and low content of heavy metals. It is excavated and stored the "secondary deposit", and partly used for production of Ecocalcium carbonate fertiliser.

Miocene siderite iron ores occur within the Turów lignite deposits in form of small benches, isolated concretions, and quartz-sideritic sand (Jęczmyk, Kasiński, 1995). Siderite concretions were exploited during 1950-ties and used for enrichment of Jurassic iron ores processed in Poland at that time.

Jurassic limestones and Upper Cretaceous gaize occur within the walls of the tectonic trough filled by the Bełchatów deposit. Their exploitation is controlled by slope contour, and the total production volume reaches up to 300,000 Mg per year. This material may be used for road construction.

Neogene quartzites are dispersed within the coal seam and underlying beds in the Bełchatów deposit. They may be used for road construction.

Smectite/haloisite weathering crust occur on a surface of the basalt laccolith, cropped out in the Turów open cast mine; after some further technological tests, it may be used for coagulants and discharging earth production.

Peat and carbonate gyttja occur within Quaternary overburden rocks in some deposits, particularly in the Konin lignite-bearing region and in the Bełchatów deposit. It is used as one of components of some kinds of natural fertilisers.

Granite boulders from Quaternary rocks are exploited in the Bełchatów mine in volume of 20,000 Mg per year. They may be used as crushed stone for building, road construction, and stonework.

Concentrations of re-deposited amber grains are known from the lowermost part of the Quaternary deposits within the Bełchatów lignite deposit.

Slightly mineralised drinking water, pumped in the Bełchatów deposit with a discharge of 2.0–2.5 m^3/min from the Cretaceous basement, at the depth of 312 m, is used for production of table drinking water and some kinds of soft drinks.

Great volume of overburden rocks, stored within external and internal dumps, is in fact utility refuse material, used for soil constructions (embankments, ramparts etc.) inside and outside the mines.

Excavation of by-products usually many times exceeds the local requirements, limited by transportation costs. Therefore, "secondary" anthropogenic deposits (storages) use to be built in the lignite mines for protection of those resources. After the long-time development, the stored by-product resources will allow to prolong economic activity of the mines, after total exhaustion of lignite reserves (Pajda, Ratajczak, 2000).

ECONOMIC CONTROL OF EXPLOITATION

Forecasted balance of energy displays that the future requirements in Poland, during the next 30 years, will be more or less constant, and its potentially increasing demand may be covered with the renewable energy resources (Jaworski *et al.*, 1998). In the future, electricity production based on hard coal combustion, will systematically decrease, and new energy resources (mostly natural gas) will cover only a part of this deficit (Rybicki, 1998). However, even after 2030, ca. 60% energy will be produced with combusting of coal (bituminous coal and lignite) (Jaworski *et al.*, 1998; Smakowski, 1998), and total requirement of lignite will rather be higher than today.

Moreover, electricity produced on the base of lignite combustion is presently, and will be in the future, the cheapest one. Its production costs were in 1998 equal to 76.58 PLN/MWh (ca. 19 USD/MWh), what is about 68.5% of the costs of power production based on high-rank coal. Four of the five power plants working on lignite produce cheaper energy than the cheapest one of the working on hard coal (Fig. 10).

In Poland, due to favourable mining and geological conditions as well as advanced mining technology, open cast mines produce lignite at much lower cost, calculated into both the calorific and heating values, in comparison to all other fuels. After the economic analyses (Bielikowski *et al*., 1999), the lignite is expected to be the source of the cheapest energy in Poland in the foreseeable perspective.

Future mining of lignite resources needs a proper valorisation of more than 140 known not-exploited deposits (Piwocki, Kasiński, 1993, 1994). Mining cost parameters should be most substantial (but not sufficient ones) for the deposit ranking (Mazurek, 1997a; Mazurek, Kasztelewicz, 2000). Among them, the overburden removing costs should be mostly consi-

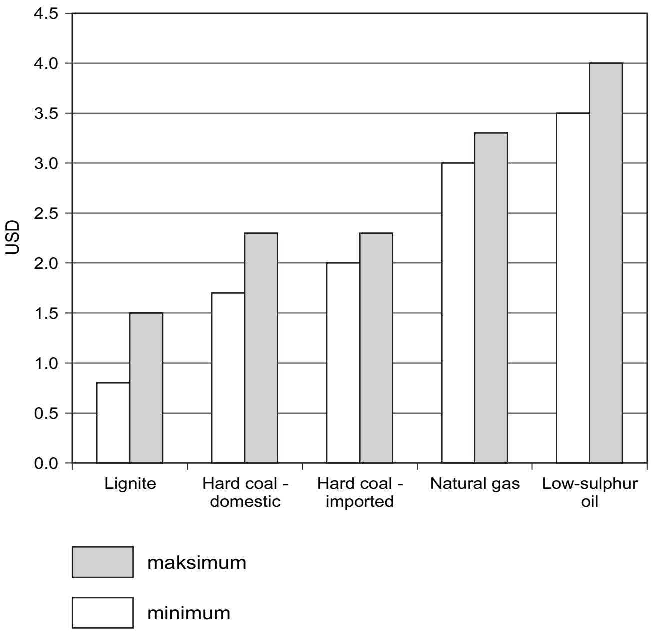

Fig. 10. Cost of 1 GJ of energy; comparison of the different energy sources (after Bielikowski *et al.*, 1999)

dered in the Polish conditions, as they generate 60–80% of total mining cost (Kozłowski, Wagenknecht, 1996), and the volume of removed rocks depends mostly on the depth of mining.

Therefore, an approximate economical value of any deposit may be calculated on a base of linear stripping ratio value, what used to be calculated in any geological report during geological studies or prefeasibility study stages. This procedure makes possible to complete the economic ranking of lignite deposits in Poland. After such a ranking, the Cybinka, Legnica Zachód, Radomierzyce, Gubin, and Torzym deposits (see Fig. 1) should be first opened in the future (Mazurek, 1997b). Also questions of economic profitability of future lignite mines are considered during the early stages with the discontinued cash flow method (DCF) (Jurdziak, 2000), as the whole procedure of an open cast mine construction needs usually 10–12 years (Uberman *et al.*, 1995). Design parameters of open-pits are calculated on a base of digital models of lignite deposits (Specylak, Kawalec, 1999).

ENVIRONMENTAL IMPACT

Two major groups of environmental impact: primary and secondary (Table 5), are related to mining and combustion of lignite (Kasiński, Piwocki, 1992).

Primary impact is affected with mining processes only. Its value is a sum of direct and indirect impacts. The direct impact is caused by a long-time surface transformation, related to open pit and external dump construction, and to development of areas occupied by mine infrastructure. Mining activity used to occupy a land for 10–20 years, depending on geological conditions of lignite deposit. After this time, occupied land is delivered to agriculture or forest administration.

The indirect impact occupies much wider area, practically covering the extension of groundwater depression cone. It consists of a complex hydrological and hydrogeological transformations, related to (1) lowering of groundwater table, (2) soil drying after drainage of shallow groundwater, and (3) reducing the amount or even disappearing of the surface water.

Table 5

Main directions of environmental impact and counteraction procedures

Impact type		Environmental effect		Counteraction procedure
"Primary"	direct	long-time surface transformation		proper reclamation of the deteriorated area
	indirect	hydrogeological	lowering of groundwater table	construction of water-supply network after the end of exploitation
			soil drying due to drainage of shallow groundwater	reconstruction of the aquifers
			decreasing and/or deterioration of surface water	reconstruction of the surface stream net-work
		geomechanic	land-surface subsidence	
			landslides (on the slopes of open-pit and external dumps)	technologies of landslide stopping supporting overburden ramparts (Larsen's walls *etc.*)
		shocks and local earthquakes		
		air contamination	dust contamination during exploitation and overburden storage	sprinkling of overburden masses during storage
			gas contamination during self-burning of coal cropped out in open-pits	monitoring and quick putting of the self-burning of coal cropped out in open-pits
		surficial water	mostly with suspended matter — by mining water	sedimentary ponds, usually with a plant filter
			mostly with suspended matter — by water from external dumps	
		noise		acoustic screens, disconnection of the most-noisy installations by night
"Secondary"	air contamination	dust contamination during lignite transportation and combustion in the power plants		dust-screens along the conveyer lines; dust electrofilters with the 99.98% performance
		gas contamination during coal combustion and self-burning of coal at the storage dumps		desulphurisation technologies for coal combustion, substantially reducing the SO_2 emission; advanced technologies of coal combustion: fluidal-bed technology; minimising the SO_2 and NO_x emissions
	water contamination	thermal contamination of surface water by hot power-plant waters		introduction of the new species of fauna (fishes), controlling of excessive growth of the alga flora
		chemical contamination of groundwater by waters from the ash-store fields		construction of tight store-plants

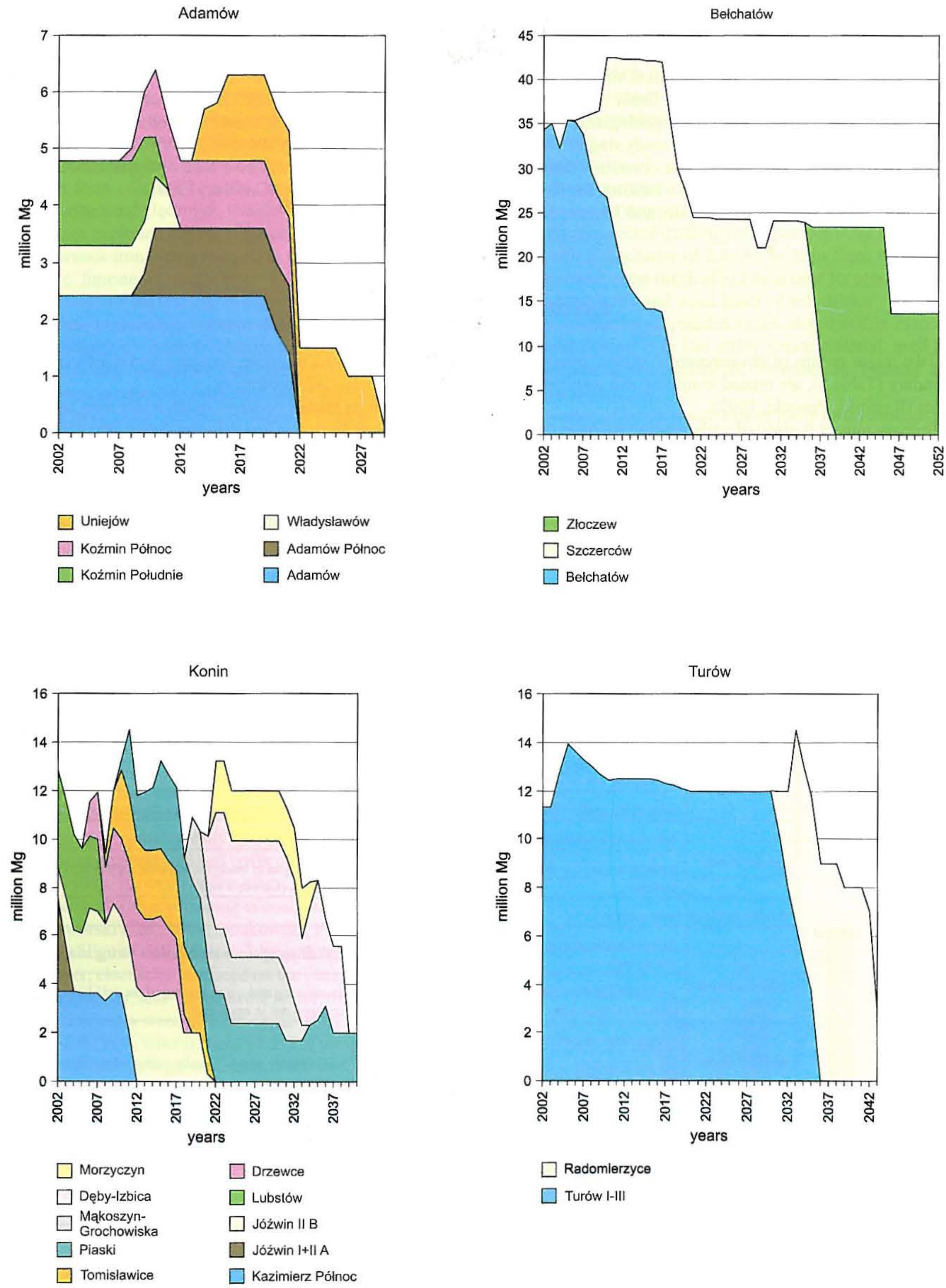

Fig. 11. Forecasted lignite exploitation in the Polish operating mines (partly after Kasztelewicz, 1997)

Geomechanical deformations are also important. They are: (1) land-surface subsidence after deep dewatering of overburden and deposit rocks within the whole depression-cone area, and (2) landslides on the open-pit and external dumps slopes. In the large and deep lignite mines, (3) shocks and local earthquakes are caused by great mass transformation, substantially changing stress field.

Moreover, mining causes air contamination: (1) dust contamination during exploitation and overburden storage, and (2) gas contamination during self-burning of coal cropped out in open pits, and also (3) surface water contamination, mostly with matter suspended in water from open pits and from external dumps. Noise connected with work of excavators, conveyers, and dump machines (and also with periodical shots) is another environmental effect of mining procedures.

Secondary impact is related to lignite transportation, storage, and combustion, what take place mostly in mouth-mine power plants. It consists of widespread air contamination: (1) dust contamination during lignite transportation and combustion in the power plants, and (2) gas contamination during coal combustion and self-burning at the storage dumps, and also of surface water and groundwater contamination: (3) thermal contamination of surface water (rivers and lakes) by hot power-plant water outflow, and (4) chemical contamination by water penetrating from the ash-store fields.

Environmental impact on law-protected objects is also one of the important factors taken into account in ranking the lignite deposits (Kasiński, Piwocki, 1992). Its intensity is not easy for precise evaluation. It may be estimated approximately only, with sufficient precision for the primary ranking (Piwocki, Kasiński, 1993, 1994).

The commonly-used technologies (*vide* Table 5) are increasing the environmental impact of mining and of lignite combustion.

The international conventions, accepted by Polish authorities, require to substantially decrease emission of harmful gases. Therefore, working power plants are recently deeply reconstructed adapting the new technology of lignite combustion on fluidal bed. This technology will enable substantially decrease the SO_3 and NO_x emission, fulfilling the requirements of the 2nd Sulphur Protocol, signed by Poland in 1994 in Oslo.

PERSPECTIVES FOR THE FUTURE

Exploration of lignite resources in satellite deposits located around the operating mines is particularly valuable for development of lignite industry during the coming future. New discoveries will make possible to extend the activity of operating mines.

In longer perspective, potential exploitation of new lignite deposits will be mostly connected with the Western and North-western regions, in the vicinities of Gubin, Legnica, Poznań, Słubice, and Trzcianka. However, mining of these deposits is somewhat problematic considering requirements of environmental protection in respect of negative impact of mining and lignite combustion. The vicinities of Gubin, Słubice, and Trzcianka are truly scenic lakeland areas, covered with large forests and full of clean waters. The Poznań vicinity is an area of high-quality arable lands which should be protected against changes of hydrogeological conditions. In this light, the deposits near Legnica look like the most probable subjects of further exploitation (Piwocki, Kasiński, 1994; Mazurek, 1997b). Area of Gubin and Słubice will probably be also considered in longer perspective.

Reserves of the operating mines will substantially decrease between 2018 and 2028 (Fig. 11). The last date is the latest starting time for the Legnica mining/energy complex. Total economic resources of the deposits are of 4.1 mil. Mg, and they may assure exploitation up to 2093, covering the requirements of the new mouth-mine power plant with capacity ca. 3000 MW.

The chance to continue any such activity depends on social acceptance. In case of lignite, all the operating open cast mines meet with a positive social response. On one hand, this social acceptance is the result of common understanding of local communities that mining in their area creates a chance for a further development and for high employment rate. On the other hand, it derives from the knowledge that the quality of life in mining regions, considering even all environmental loses, is much higher than in purely agricultural ones.

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