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Stanisław PRZENIOSŁO, Anna DZIEDZIC, Antoni PIZON

Management of the native sulphur deposits in the Carpathian Foredeep during the period 1953–1993

Intensive exploration and prospect works, carried out in the Carpathian Foredeep up to 1975, resulted in the discoveries of new native sulphur deposits, enlarging the national sulphate resources. In 1976 the identified economic reserves of sulphur in these deposits was estimated at 984.3 mln t. The resources of identified deposits, together with the output until this time (over 34 mln t) and the exploitation loss (larger than output), were calculated at over 1 mld t. After 1976 the sulphur resources gradually decreased. Further research has not located new deposits and the prospect of enlarging total resources seems to be uncertain, especially to depths of 500 m.

This article presents the phases of the examination and management of sulphur resources during the last forty years as well as the volume changes of sulphur output, national consumption and export. About 75% of sulphur production is exported (in the last decade this volume increased from 69 to 78.6%). Ecological concerns, other sources of sulphur production and the drop of the world trade price for sulphur, suggest, to the authors, significant decrease of output in the future. Although such a situation prolongs the time until deposit exploitation, it enables the proper resource protection and optimizes the indexes of resource utilization. From the other side, the recession in the sulphur industry may disturb the positive balance of the export and import of chemical minerals, and it could involve social-economical troubles.

NATIVE SULPHUR RESOURCES IN THE CARPATHIAN FOREDEEP

Native sulphur deposits, which occur in the Badenian post-gypsum limestones, were discovered in the northern part of the Carpathian Foredeep in 1953. The history of these discoveries was described by S. Pawłowski (1981, 1983) and B. Kubica (1981).

During the first four years the resources of the deposits in Solec near Szydłów, in Piaseczno, Grzybów and Świniary were describe. Further research has continued since 1964, after a short pause from the previous decade. The diagram of variability of sulphur resources (Fig. 1) illustrates both the stepwise increase of total geological resources,

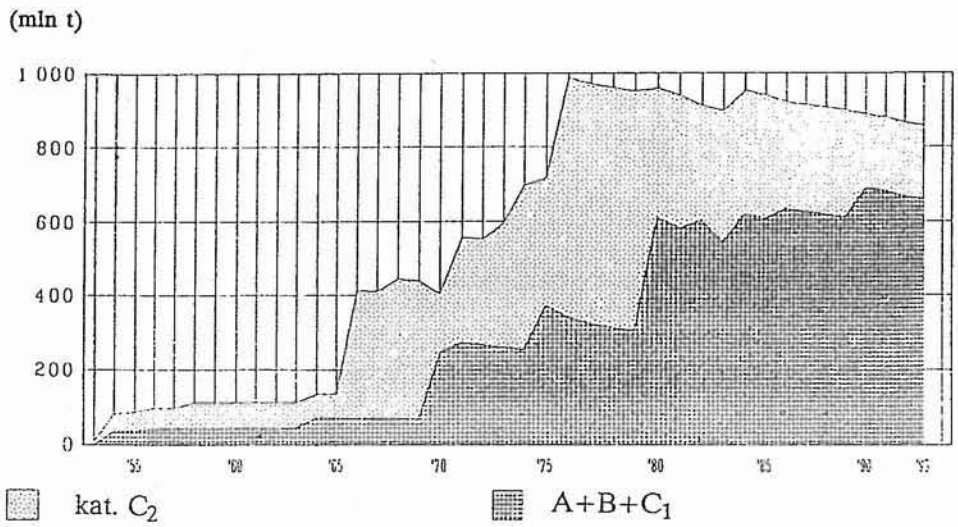

Fig. 1. Variations of the native sulphur resources in the deposits of the Carpathian Foredeep in the period 1953–1993
Zmienność stanu zasobów siarki rodzimej w złożach zapadliska przedkarpackiego w latach 1953–1993

indicating the location of new deposits, as well as the detailed recognition of deposits already prepared for exploitation. Resource increases of the years: 1966, 1971, 1974 and 1976, correspond to the discoveries of the sulphur deposits at Jeziórko, Jamnica, Rudniki, Basznia, and Osiek – Baranów Sandomierski. In the second case, the rapid enlargments of resources (in C_1 and higher categories) took place in 1970, 1975 and 1980 and they referred to previously found deposits.

Industrial sulphur concentrations occur in several regions, each with individual sulphur deposits. They are as follows (in order of maximum economic value):

— the Tarnobrzeg region, including the sulphur deposits: Piaseczno, Machów – Mokrzyszów, Jeziórko – Wydrza – Grębów, and Jamnica;

— the Baranów Sandomierski region, with the deposits: Niekrasów, Osiek, and Baranów Sandomierski – Skopanie;

— the Lubaczów region with the Basznia deposits;

— the Staszów region with the deposits Solec and Grzybów;

— the Połaniec region with the Rudniki deposits.

The resources of the located and documented native sulphur deposits in the Miocene series of the Polish part of the Carpathian Foredeep was calculated at over 1 mld t. In 1976 the largest resource volume was documented — 984 thousand tons, and since that time over 34 mln t of sulphur have been mined. After 1976 a gradual decrease in sulphur resources from Polish deposits was observed. Continued research has not found significant new deposits and the prospect of expanding current resources seems to be doubtful, especially from the depth interval 0–500 m.

The state of the economic geological resources as of 31.12.1992, and their degree of recognition and productivity (S. Przeniosło, 1993) is presented in Table 1. The resources

Table 1

Sulphur (in 1 000 000 t) — state on 31 December 1992

Content	Number of deposits	Resources			
		economic			non economic
		total	$A+B+C_1$	C_2	
I. IDENTIFIED RESOURCES – TOTAL	12	862.97	665.64	197.34	37.39
inclusive of exploited deposits resources					
Total –	6	496.95	496.06	0.89	30.96
inclusive:					
1. mines	5	435.30	434.41	0.89	30.42
2. under construction	1	61.65	61.65	0.00	0.55
inclusive of non exploited deposits resources					
Total –	5	366.02	169.58	196.45	0.00
inclusive:					
1. detail recognized	2	169.58	169.58	0.00	0.00
2. preliminary recognized	3	196.45	0.00	196.45	0.00
inclusive abandoned deposits resources					
Total –	1	0.00	0.00	0.00	6.43

of individual deposits, including free resources and those left within the protecting pillars, are documented in Table 2.

MANAGEMENT OF DEPOSITS AND EXPLOITATION METHODS

The Piaseczno deposit was the first exploited deposit, where, on 4.12.1957, open pit method sulphur production began. The second open pit mine was located in the Machów deposit. This method of sulphur mining was possible due to shallow occurrence of thick sulphur-bearing limestones (in Piaseczno their average thickness was 45 m, in Machów they were from 50 to 120 m thick). Exploitation was stopped in Machów in 1992 despite significant resources being left. This decision was made for economic reasons, because production costs were twice as high as costs using the method of underground melting and distinctly exceeded sulphur prices on the world market.

Open pit mining was continued for 35 years, with maximum annual output of 0.9 mln t and a total volume of about 19 mln t (Fig. 2) according to the *Bilans zasobów kopalin...* (S. Przeniosło, 1993). The open pit method is characterized by small exploitation losses, estimated at 7% for the Piaseczno deposit (Fig. 3) and the exploited parts of the Machów pit.

Table 2

Native sulphur reserves in the deposits of Carpathian Foredeep (state on 31 December 1992)

Name of deposit	Development state	Identified economic reserves		
		total	outside pillars	inside pillars
Baranów Sandomierski–Skopanie	detail recognized	169498	99231	70267
Basznia	exploited	102544	102544	0
Grzybów–Gacki	exploited	4151	3743	408
Jamnica	preliminary recognized	137770	137770	0
Jeziórko–Grębów–Wydrza	exploited	251143	194930	56213
Machów I (open pit)	abandoned	18602	13965	4637
Machów II (frash methode)	exploited	58857	41261	17596
Osiek	under construction	61652	52912	8740
Piaseczno	abandoned	non economic resource only		
Rudniki	preliminary recognized	53100	49950	3150
Solec	preliminary recognized	5576	5576	0
Świniary	detail recognized	80	80	0

The underground melting method of sulphur production was started in 1966 in the Grzybów mine and in 1967 in the Jeziórko mine (E. Gutman, B. Kwieceń, 1992). This method may be applied in variable geological-mining conditions (J. Kirejczyk, 1991). Rate of production using this method can easily be adapted to short-term variations of the market. Since 1962 it has been the only method used in Polish sulphur deposits.

The index of resource utilization for this method is difficult to evaluate for the period of its application. This index for the 1976–1992 period is estimated at 44%. This means that the production of 1 t of sulphur results in 2.28 t of resource loss. This does not preclude the possibility of re-exploitation of some ore fields and the improvement of their utilization index.

Total sulphur production with both methods was — until 1992 — over 106 mln t (Fig. 2). The aim of the management of Polish sulphur deposits according to the rules of the

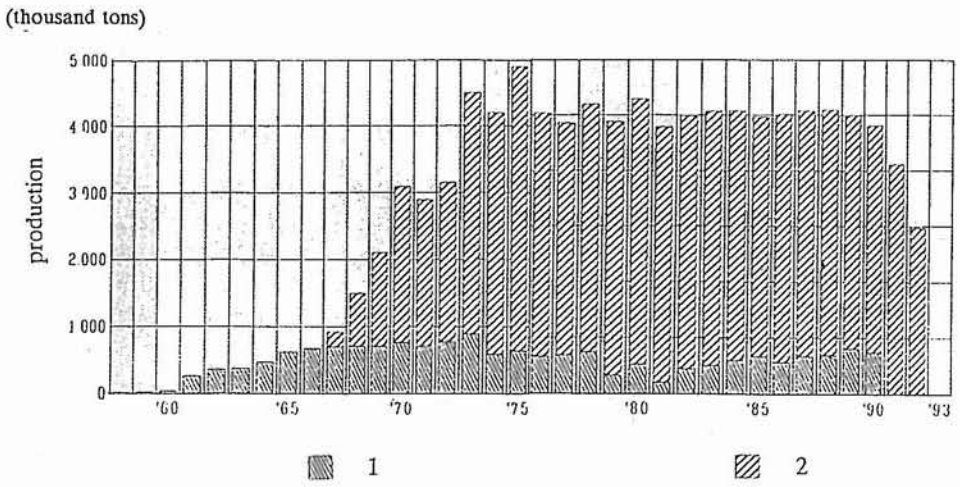

Fig. 2. Sulphur production from deposits in the Carpathian Foredeep during the period 1958–1993
1 — open pit mines, 2 — underground melting
Wydobycie siarki ze złóż zapadliska przedkarpackiego w latach 1958–1993
1 — metodą odkrywkową, 2 — metodą otworową

central planning was to obtain the maximum foreign-currency input into the national budget (J. Kirejczyk, 1992). Most produced sulphur is exported (Fig. 4). "Apparent consumption" presented in Figure 4 includes real consumption by national industry and reserve volumes of producers and national users. Poland is the second largest world exporter (after Canada) and the condition of the Polish sulphur industry is determinated by the value of sulphur on the world market.

WORLD SULPHUR PRODUCTION AND PRICES

Native sulphur, mined from deposits makes up over 90% of total sulphur production in Poland (A. Bolewski *et al.*, 1988; K. Galos *et al.*, 1990). In other countries, this form of sulphur production is less popular and was only 25% of world production during the last decade. Other sources of sulphur, such as petrochemical covery from desulphurization processes of natural gas and oil (50% of world sulphur production). This is for both economical and ecological reasons. The ecological factor is undisputable — protection of the natural environment from the harmful sulphur industry. The economical reason is the improvement of gas and oil product quality and is very important because the costs of sulphur production in this way are significantly lower than the costs of its excavation from the native sulphur deposits or from pyrites.

The second important sulphur source is sulphur recovery from metallurgical processes, mainly of non-ferrous metal sulphides. The most common product is sulphuric acid and other sulphur components. A smaller amount of sulphur is obtained from other sources such

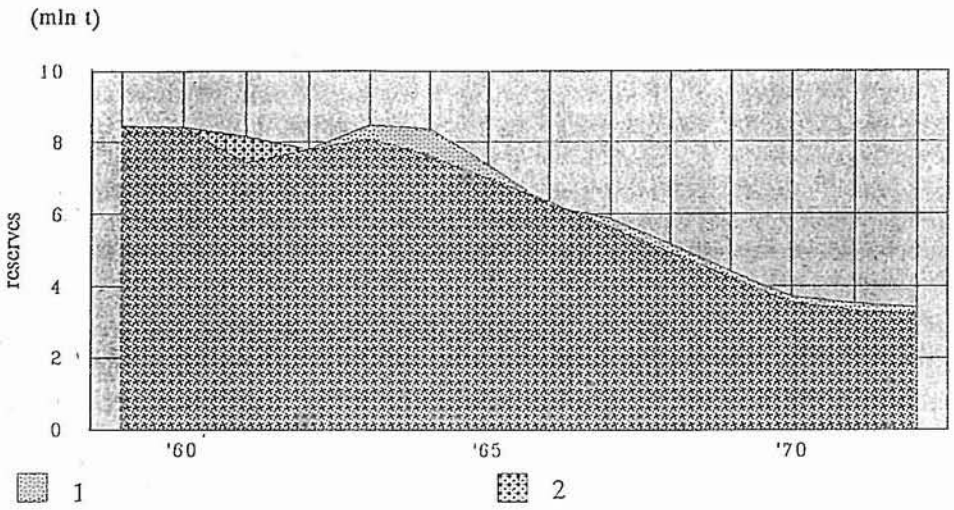

Fig. 3. Variations of the geological resources of native sulphur in the Piaseczno deposit during the period 1959–1972
1 — after data of the resource list, 2 — calculated resources (without losses)
Zmienność stanu zasobów geologicznych siarki rodzimej złoża Piaseczno w okresie eksploatacji 1959–1972
1 — według ewidencji zasobów, 2 — zasoby wyliczone (bez uwzględniania strat)

as cokeries. The sulphur products from these sources are frequently contaminated — for instance, with heavy metals — but they are often useful to industry. This is the situation characteristic of Polish non-ferrous metal industry (i.e. copper, lead, zinc), with its large possibilities of sulphur recovery.

Pyrites are an even less important source of sulphur and its products. The United States stopped production by this method in 1987, and the countries of the former USSR limit it. Only China obtains most of its sulphur from this source and sulphuric acid production will be based for a long time on the large pyrite resources in that country.

Poland has the most unfavourable pattern of sulphur resources among the main world producers (Tab. 3; data after A. Dziedzic, S. Przeniosło, 1993 — supplemented). Petrochemical recovery in Polish refineries is up to 66 thousands tons per year (hitherto only half of this volume was obtained). Petrochemical recovery of sulphur in Canada is one of the main reasons for present troubles and of sulphur price decrease on the world market (Tab. 4). By the year 2000, sulphur recovery will be about 6.5 mln t due to the exploitation of new natural gas fields in Canada.

The rapid fall of the price of sulphur, to 25 USD per ton (Vancouver, the Middle East), due to production from petrochemical recovery has eliminate the cost effectiveness of native sulphur mining. Actual sulphur prices are also too low to allow petrochemical recovery in areas where the greatest cost is transport of sulphur to distant harbours, i.e. from Alberta to Vancouver in Canada. This situation caused the rapid decrease or elimination of sulphur mining in some countries. Poland is in a particularly unfavourable position because it is one of the main exporters and its distribution of sulphur resources is disadvantageous.

The changing of directions of Polish export influenced the position of the sulphur industry. Between 1987 and 1992, Polish sulphur export to countries of Eastern and Middle

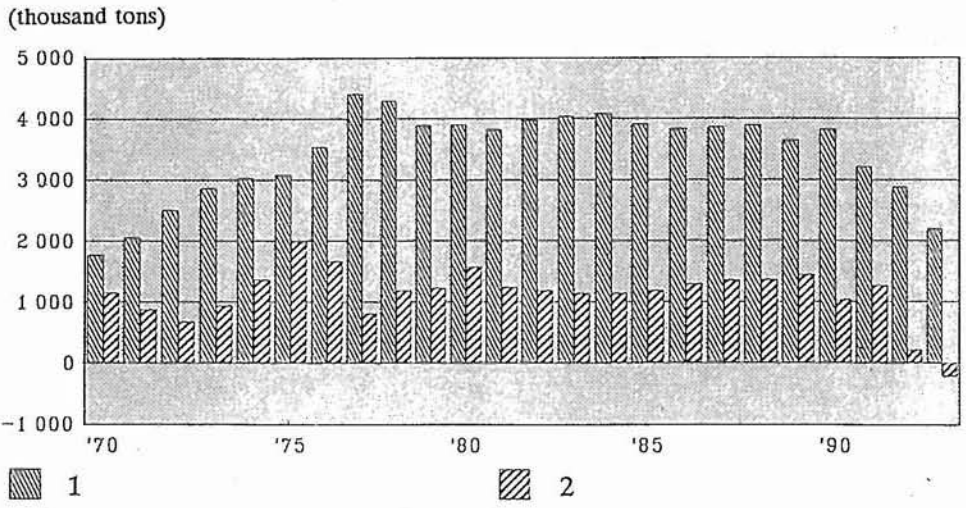

Fig. 4. Sulphur export (1) and "apparent consumption" (2) in Poland in 1970–1993
Eksport (1) i zużycie pozorne (2) siarki w Polsce w latach 1970–1993

Europe dropped from 54 to 18%, but it increased from 8 to 37% to countries of North Africa (Fig. 5). A direction which is not being taken to full advantage is Asia, particularly India.

The world sulphur requirement decreased but its geographic distribution is diverse. It dropped by about 5 mln t due to the decrease of fertilization in Eastern and Middle Europe and about 2 mln t in Western Europe (mainly due to ecological reasons). In North America it also decreased by about 2 mln t.

As small increase of sulphur consumption occurred in South America but a distinct increase was seen in Africa, especially in Marocco and Tunisia. Also higher consumption is noticed in Asia, mainly in China and India.

MANAGEMENT OF THE POLISH SULPHUR DEPOSITS IN LIGHT OF THE PROGNOSES CONCERNING WORLD SULPHUR PRODUCTION AND PRICES

A slow increase of sulphur consumption is expected in the next few years but the highest level — 63 mln t in 1988 — could be exceeded just after the year 2000.

There is no evidence for the quick and real improvement in the position of sulphur on the world trade market. The forecasted small increase in consumption will be met by sulphur recovery, being cheaper and more ecologically sound than other methods.

Sulphur prices are now at their lowest level and they will probably increase slowly. Such an increase may result from lowered sulphur supplies on the world market as a result of the end of sulphur production from some pyrite and native sulphur deposits. The re-exploitation of some closed deposits could also be possible under better market conditions i.e. the Machów open pit mine in Poland. But due to higher sulphur supply than consumption, the limited production will involve only a small price increase. Higher sulphur prices may result

Table 3

Main world producers in 1985–1992 (in 1000 t)

Country	1985	1986	1987	1988	1989	1990	1991	1992
World total	56500	55500	58300	60600	60300	58200	56700	55100
United States	11609	11087	10545	10746	11592	11560	10816	11614
– native sulphur	5011	4043	3202	3174	3888	3726	2869	2323
– from pyrite	328	309	179	3	4	4	b.d.	b.d.
– from oil and gas	5313	5816	6161	6444	6510	6536	6645	7110
– from smelter gas	957	919	1003	1125	1190	1294	b.d.	b.d.
USSR/CIS	9205	8663	9750	10765	9900	9025	9000	8331
– native sulphur	2760	3500	3500	3500	3450	3000	2700	
– from pyrite	2421	2090	2150	2150	2150	1900	1700	
– from oil and gas	2324	2025	2850	3740	2950	2925	2600	
– from smelter gas	1700	1050	1250	1375	1350	1200	b.d.	
Canada	8912	7776	8107	8986	7709	8137	7100	7431
– from oil and gas	8102	6966	7322	8107	6869	7168	6165	6535
– from smelter gas	810	810	785	879	836	969	935	896
China	2900	3100	4500	4750	5165	5423	5470	6189
– native sulphur	200	300	300	300	330	329	320	340
– from pyrite	2350	2500	3700	3900	4271	4460	4500	
– from smelter gas	350	300	500	550	561	622	650	
Poland	5208	5264	5344	5370	5252	5038	4350	3091
– native sulphur	4960	5015	5075	5094	4995	4810	4115	2870
– from oil and gas	28	30	29	33	34	29	29	30
– from smelter gas	220	219	239	243	223	198	206	191

Source: World Mineral Statistic, US Bureau of Mines, PIG–MIDAS, PIG–PRICESMIN, Sulphur 229/1993

Table 4

Average prices of sulphur in 1991–1993 (fob ports producers, in USD/t)

Contract (cash equivalent)	1991		1992		1993	
	I half	II half	I half	II half	I half	II half
Solid:						
– Vancouver	90–106	70–73	62–63	38–55	28–40	25–33
– Gdańsk	90–106	65–75	58–63	45–55	30–45	28–35
– Tampa (US Gulf)	105	70–73	61–62	40–45	b.d.	b.d.
– Middle East	85–108	70–75	58–65	40–65	30–48	25–35
Liquid:						
– ex–term NW Europe	122–130	105.75	92	82	55–67	45–58
– ex–term US Gulf	125.9	96–123	96	86–96	64–86	52–83

Source: Sulphur

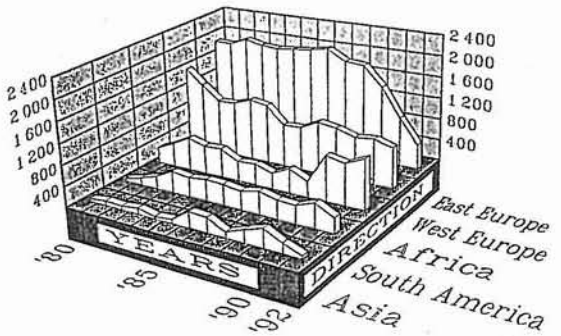

Fig. 5. Directions of sulphur export (in thousand tons) from Poland in 1980–1992
Kierunki eksportu polskiej siarki (w tys. t) w latach 1980–1992

from increased demand for fertilizers in Middle and Eastern Europe, Russia and its partners, in the United States and in some countries of Asia and South America.

The prediction of world trends of sulphur production and prices up to the year 2000 is a difficult task due to volume variations of obtained sulphur. This refers mainly to the production from petrochemical and metallurgical recovery but also to sulphur obtained from deposits by the underground melting process.

Prognoses for produced sulphur volume up to the year 2000 (Fig. 6) are based on the analysis of sulphur production from various sources. An almost constant level of production from pyrite deposits and from recovery of sulphides in non-ferrous metallurgical processes is assumed. In the case of pyrite deposits, such production has stopped in the United States and western countries and it is limited in the area of the former USSR. However, a significant amount of sulphur is obtained from this source in China.

Despite some limitations in the use of sulphuric acid, produced from sulphides, it is expected that the production from sulphuric acid factories, located at copper plants, will increase over 20%. According to published data (*Sulphur*,) the most important new factories of this type are: Chuquicamata (Chile), Garfield and El Paso (USA), Ratnagiri (India), Głogów and Legnica (Poland), and Tamano (Japan).

The volume of sulphur recovered from natural gas and oil, will increase by the year 2000 (A. Inoue, 1992) to 34.5 mln t per year. In 1990 this source supplied 40% of global sulphur production, in 1995 it is will be 54% and in 2000 this volume will be about 60% of total production. The main sulphur producers of this type will be: Canada (from deposits in Alberta), Russia (from the Astrachan deposit), Kazakhstan (from the Tengiz deposit), USA and countries of the Middle East such as: Abhu Dabi, Saudi Arabia, Qatar, Iraq and Iran.

The most important producers native sulphur deposits are Poland, USA, Mexico, Iraq and Russia. Recently, sulphur production from this source has dropped significantly. In the near future it could decrease to 7 mln t but later it may increase to 8–10 mln t per year. Such variations will depend on general trends of sulphur production and prices.

A sulphur price lower than 30 USD could not be tolerated for a long time because it does not reflect the costs of production from native sulphur deposits and the transport costs

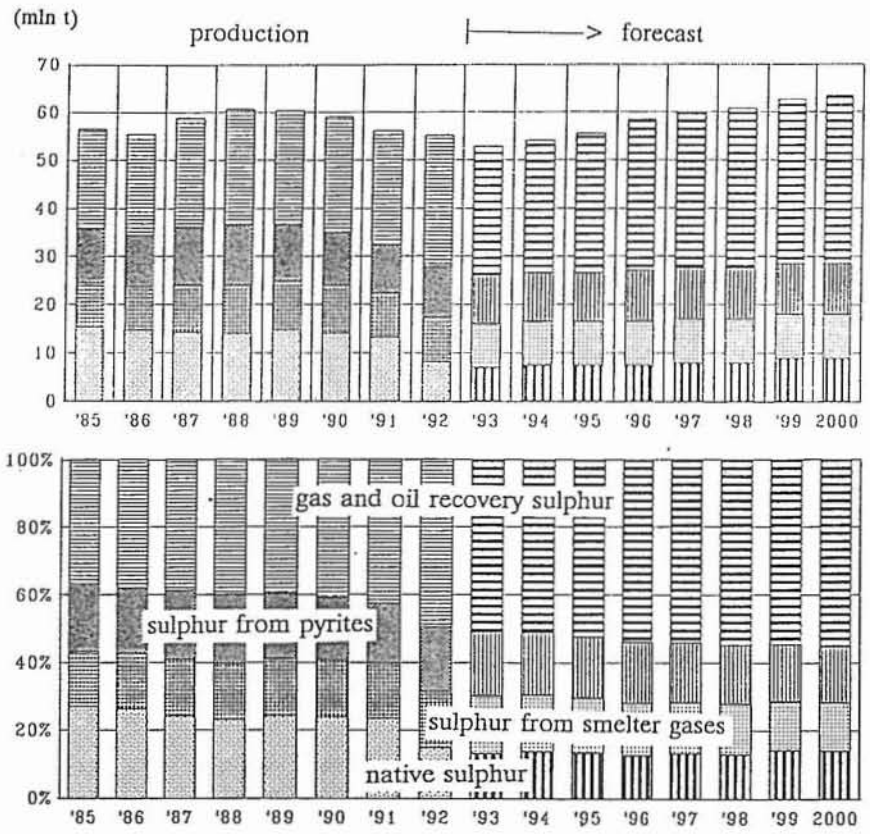

Fig. 6. Value and content of various sulphur sources in world sulphur production in 1985–1992 and the prognoses up to the year 2000
Wielkość i udział różnych źródeł pozyskiwania w światowej produkcji siarki w latach 1985–1992 i prognozy do 2000 r.

of sulphur from deposits to distant harbours. According to the authors, this price should increase to 50–60 USD in the year 2000. It depends on limiting sulphur production and requires the co-operation and co-ordination of producers' activity.

Poland has large resources of native sulphur deposits which occur in favourable geological conditions. It is uncertain whether they will play a significant role on the forseeably favourable world market (B. Kubica, 1994). According to the authors, the Polish

sulphur industry will concentrate on limiting production and preserving mining potential that it could be easily activated at the moment of favourable market changes. But such a situation is expected no earlier than the turn of the century.

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Zakład Geologii Gospodarczej
Państwowego Instytutu Geologicznego
Warszawa, ul. Rakowiecka 4
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Stanisław PRZENIOSŁO, Anna DZIEDZIC, Antoni PIZON

ZAGOSPODAROWANIE ZŁÓŻ SIARKI RODZIMEJ ZAPADLISKA PRZEDKARPACKIEGO W LATACH 1953–1993

Streszczenie

Złoża siarki rodzimej, występujące w północnej części zapadliska przedkarpackiego, zostały odkryte w 1953 r. w rejonie tarnobrzeskim, głównie w wapieniach pogipsowych wieku tortońskiego (S. Pawłowski, 1983). Zapoczątkowało to intensywne prace poszukiwawcze i rozpoznawcze, trwające aż do 1975 r., które zaowocowały nowymi odkryciami oraz dokumentacjami, powiększającymi stan zasobów. W 1976 r. udokumentowane zasoby bilansowe były najwyższe i wynosiły 984,3 mln t siarki. Uwzględniając wydobycie (ponad 34 mln t) od początku eksploatacji aż do tego roku, a także większe od wydobycia straty eksploatacyjne, zasoby udokumentowanych w tym rejonie złóż przekroczyły miliard ton. Od 1976 r. nastąpił stopniowy spadek zasobów siarki rodzimej w złożach polskich. Prace poszukiwawcze nie doprowadziły do odkrycia złóż nowych. Perspektywy ich powiększenia są niewielkie, szczególnie w strefie głębokości dotychczas udokumentowanych złóż, czyli do 500 m.

W opracowaniu przedstawiono zmienność stanu rozpoznania i zagospodarowania zasobów w omawianym czterdziestoleciu, a także żmienność wydobycia (fig. 2, 3) oraz krajowego zużycia i eksportu siarki. Ten ostatni ma podstawowe znaczenie dla gospodarki zasobami siarki rodzimej i wynosi ponad 75% produkcji (fig. 4). Bilansowe zasoby geologiczne na dzień 31.12.1992 r. oraz stopień ich rozpoznania i zagospodarowania według *Bilansu zasobów kopalin...* (S. Przenosło, 1993) zamieszczono w tabeli 1, a zasoby złóż, z uwzględnieniem zasobów wolnych i zasobów w filarach ochronnych, w tabeli 2.

Zagospodarowanie złóż krajowych rozpatrzono w świetle prognozy wielkości produkcji światowej i cen siarki w obrocie międzynarodowym. Wśród głównych producentów siarki (tab. 3) Polska ma najmniej korzystną strukturę pozyskiwania. Odzysk petrochemiczny w naszych refineriach z uwagi na instalacje do odsiarczania jest możliwy do ok. 65 mln t rocznie i jest wykorzystywany zaledwie w połowie. Jedną z głównych przyczyn obecnych perturbacji i spadku cen siarki na rynkach światowych (tab. 4) jest produkcja kanadyjska oparta na odzysku z produktów przemysłu petrochemicznego. Gwałtowne obniżenie cen siarki do 25 USD za tonę (Vancouver, Bliski Wschód, spot), które może być jeszcze akceptowane przez produkcję z odzysku petrochemicznego, jest jednak nie do przyjęcia przez górnictwo siarki rodzimej. Z tego powodu nastąpił gwałtowny spadek produkcji górniczej tego surowca, a nawet w niektórych krajach jej całkowite wstrzymanie. Polska znalazła się w szczególnie niekorzystnej sytuacji, albowiem przy tej złej strukturze źródeł pozyskiwania siarki jest jednocześnie jednym z głównych eksporterów tego surowca. Na kondycję polskiego przemysłu siarkowego wpłynęła też konieczność zmian kierunków polskiego eksportu (fig. 6). Do chwili obecnej nic nie wskazuje na możliwość szybkiej poprawy koniunktury siarkowej na rynkach światowych. Przewidywany niewielki wzrost zużycia będzie pokrywany wymuszoną względami ekologicznymi i tańszą w produkcji siarką z odzysku. Ceny siarki, które spadły do rekordowo niskich, będą zapewne wkrótce wzrastać.

Przeprowadzono analizę pozyskiwania siarki z różnych źródeł i przedstawiono prognozę produkcji do 2000 r. Względy ekologiczne, wykorzystanie innych źródeł pozyskiwania tego surowca oraz spadkowe trendy cen siarki w obrocie międzynarodowym wskazują, zdaniem autorów, na konieczność zredukowania wydobycia i utrzymania potencjału wydobywczego, który można by uruchomić przy zmianie koniunktury. Wpłynie to z jednej strony na wydłużenie okresu ich wystarczalności, ochronę i poprawę wskaźników ich wykorzystania, z drugiej zaś — w wyniku recesji gospodarczej w przemyśle siarkowym — zaburzy tradycyjnie dodatnie saldo naszego eksportu i importu surowców chemicznych i może spowodować trudności natury społeczno-gospodarczej.