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The discovery of new sulphur deposits between the Vistula and San rivers (the Carpathian Foredeep, southern Poland) — a historical review

The studies and explorations of the Polish Geological Institute after World War II of the area between Vistula and San rivers (northern Carpathian Foredeep, southern Poland) resulted in the discovery of new native sulphur deposits. The documented giant resources became a basis for the development of sulphur mining and processing. Presented here, in chronological order, is the history of the investigation and discovery of sulphur deposits during the last fifty years (1937–1987).

INTRODUCTION

One of the first research successes of the Polish Geological Institute, just after World War II, was the discovery of new native sulphur deposits. On 29.09.1953 the A-1 borehole, drilled in Mokrzeszów near Tarnobrzeg, found Miocene sulphur-bearing limestones at a depth of 81.0–82.5 m.

Professor Stanisław Pawłowski with his team was the initiator of this research and he was an unquestioned discoverer of these deposits. This discovery, made in a previously unstudied area in the northern part of the Carpathian Foredeep, prompted intensive further examinations, which resulted in the location and documentation of giant sulphur deposits.

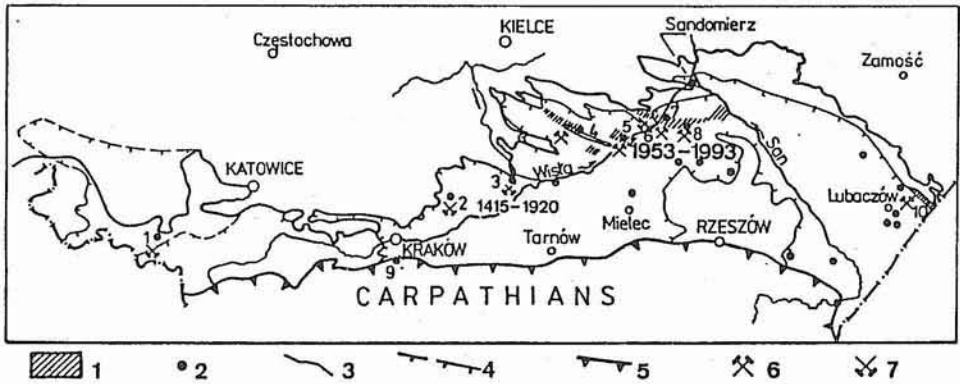


Fig. 1. The location map of the Miocene sulphur deposits and mines in the Carpathian Foredeep
 1 — native sulphur deposit, 2 — traces of native sulphur in boreholes, 3 — northern extent of the Miocene deposits, 4 — extent of the Miocene gypsum and anhydrites, 5 — the Carpathian Overthrust, 6 — active sulphur mines, 7 — closed sulphur mines: 1–10 — mines: 1 — Pszów, 2 — Posąda, 3 — Czarkowy, 4 — Grzybów, 5 — Osiek, 6 — Machów, 7 — Tarnobrzeg, 8 — Jeziórko, 9 — Swoszowice, 10 — Basznia
 Miocenne złoża siarki i kopalnie w zapadlisku przedkarpackim na tle zasięgu występowania gipsów i anhydrytów
 1 — złoża siarki rodzimej, 2 — ślady siarki rodzimej w otworach, 3 — północna granica zasięgu osadów miocenu, 4 — zasięg występowania gipsów i anhydrytów, 5 — morfologiczna krawędź nasunięć karpackich, 6 — kopalnie siarki czynne, 7 — kopalnie siarki zamknięte; 1–10 — kopalnie siarki

HISTORICAL INFORMATION

The tradition of sulphur ore mining and processing in Poland is more than 600 years old (B. Kubica, T. Osmólski, 1965). The manuscripts from Jagiellonian times document a highly organized sulphur mining industry at the turn of the 14th century but it was probably in operation earlier, during the Piast period (from the 9th century) and it was strongly influenced by the older salt mining center in Wieliczka. At that time the largest sulphur mine and factory in Swoszowice produced 1400 t of sulphur per year (equal to 4 hours of production of a recent sulphur mine in Jeziórko). The total sulphur production of all Polish historical mines during the previous 5 centuries was estimated at 200 000 t (Fig. 1).

STUDIES DURING THE LAST CENTURY

The history of studies and discoveries of the documented sulphur deposits, found in the last century, has been published briefly and in part (B. Kubica, T. Osmólski, 1965; S. Pawłowski, 1973; B. Kubica, 1974; M. Odlanicki-Poczobutt, 1978; S. Pawłowski *et al.*, 1985). This history can be subdivided for four periods: 1937–1948, 1952–1957, 1963–1976 and 1976–1993.

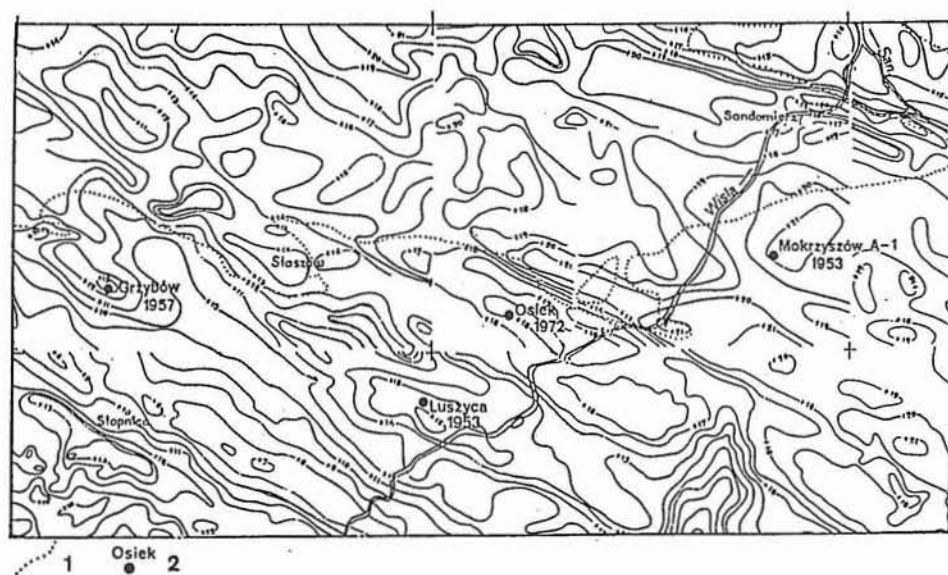


Fig. 2. The gravimetric map of the northern part of the Carpathian Foredeep (after S. Pawłowski, 1992)
 1 — the extent of the Miocene chemical deposits, 2 — boreholes with sulphur findings
 Mapa grawimetryczna północnej części zapadliska przedkarpackiego (według S. Pawłowskiego, 1992)
 1 — zasięg osadów chemicznych miocenu, 2 — otwory wiertnicze z siarką

STUDIES 1937–1948

The reconstruction of the geological structure of the Carpathian Foredeep was impossible just after World War I with the then available drilling techniques. There were no data for determining the possibilities of minerals concentrations on platform areas with huge gaps and active tectonics (mainly renewed along the older pattern).

The southern border of the Holy Cross Mts. has a complicated, "mosaic" geological structure and it was not examined in detail from a geological point of view. The deep part of the Carpathian Foredeep, infilled by monotonous deposits of the "pra-Sarmatian" (J. Czarnocki, 1935), from several hundreds up to thousands of metres thick, was "untouched" by such studies. According to some opinions (*op. cit.*) the foredeep was tectonically disturbed and a large dislocation zone was located along the Vistula river. The geophysical investigations of Prof. S. Pawłowski in this area in 1945–1950 documented many gravimetric anomalies on the southern border of the Holy Cross Mts. and in the northern part of the foredeep (Fig. 2), for instance — a large anomaly near Korytków – Biłgoraj.

The results of geophysical studies in this area enabled the distinction of several subregions with different basement structures. A constant inclination of structural elements (particularly the Palaeozoic ones) toward the south-east was identified. The characteristic anomalies, visible in gravimetric image, were significant locations for further prospecting for mineral resources. During the period 1950–1953 Poland was importing 5–10 thousands tons of sulphur per year. Such import resulted from a lack of national large sulphur deposits.

The common opinion was that all sulphur resources were totally exploited and no new deposits could be found in the vicinity of older ones (E. Passendorfer, 1946) or that "...The results of former studies, done in Posądzka, Czarkowy, Wola Wiśniowa and Czajków near Staszów, proved that sulphur mining there is aimless. Some possibilities of such activity are supposed for the largest Polish sulphur deposit in Swoszowice..." (A. Bolewski, 1949). The first conceptions of the development of the Polish chemical industry applied the technology of sulphuric acid production, based on the processing of anhydrites and gypsum from large deposits in the Nida valley.

STUDIES 1952-1957

The foundation of the Central Department of Geology in 1952 enabled wider financial support for investigations and prospections, carried out mainly by the Geological Institute.

In 1952 Prof. S. Pawłowski prepared a program of studies of geophysically interpreted structures of the under-Miocene basement from the southern border of the Holy Cross Mts. and from the northern part of the Carpathian Foredeep. The results of this program were promising:

- in June 1956 in the Luszyca borehole near Połaniec sulphur-bearing limestones were found, 1.5 m thick, at a depth of 295 m;

- the Mokrzeszów A-1 borehole drilled similar limestones, with an industrial sulphur content, at a depth of 84.6 m.

These studies documented the occurrence of new sulphur deposits between the Vistula and San rivers, about 130 km eastward from the historical centers of sulphur exploitation. They confirmed also the shallow position of Palaeozoic deposits, earlier suspected from geophysical data.

These results prompted a further and wider exploration of the shallow native sulphur deposits (Fig. 3). The sulphur finding in the Mokrzeszów A-1 borehole initiated the discovery of giant sulphur deposits near Tarnobrzeg.

The most significant events of this period:

1952 — the beginning of drilling on the geophysical structures;

1953 — June and September — the first boreholes, drilled limestones with native sulphur (in Luszyca and Mokrzeszów),

- October — first announcement about the discovery of native sulphur deposit,

- 11 November — first decision of the Central Department of Geology on special financial support for sulphur exploration,

1954 — 7 January — first documentation of the sulphur deposit in Mokrzeszów (8 exploration boreholes) elaborated by S. Pawłowski,

- 9 January — first recorded in the balance of the national resource base of sulphur — 11 mln t (i.e. about 1% of the total resource base),

- January — first conception of the development of a new industrial region in Poland (by S. Pawłowski),

- 10 April — first memorandum about the prospection of sulphur deposits in Poland (by S. Pawłowski),

- 8 May — first resolution of the government (no. 257/54), referring to sulphur exploration,

- July — first decision of the Minister of Mining (no. 288) about the foundation of the administration of future sulphur mines in Tarnobrzeg,

- December — first geological documentation of a sulphur deposit in the Tarnobrzeg - Machów region, in C₂ category.

The Central Department of Geology founded the Investment of Geological Works to document the large deposit in Machów southward from Tarnobrzeg. All these works were

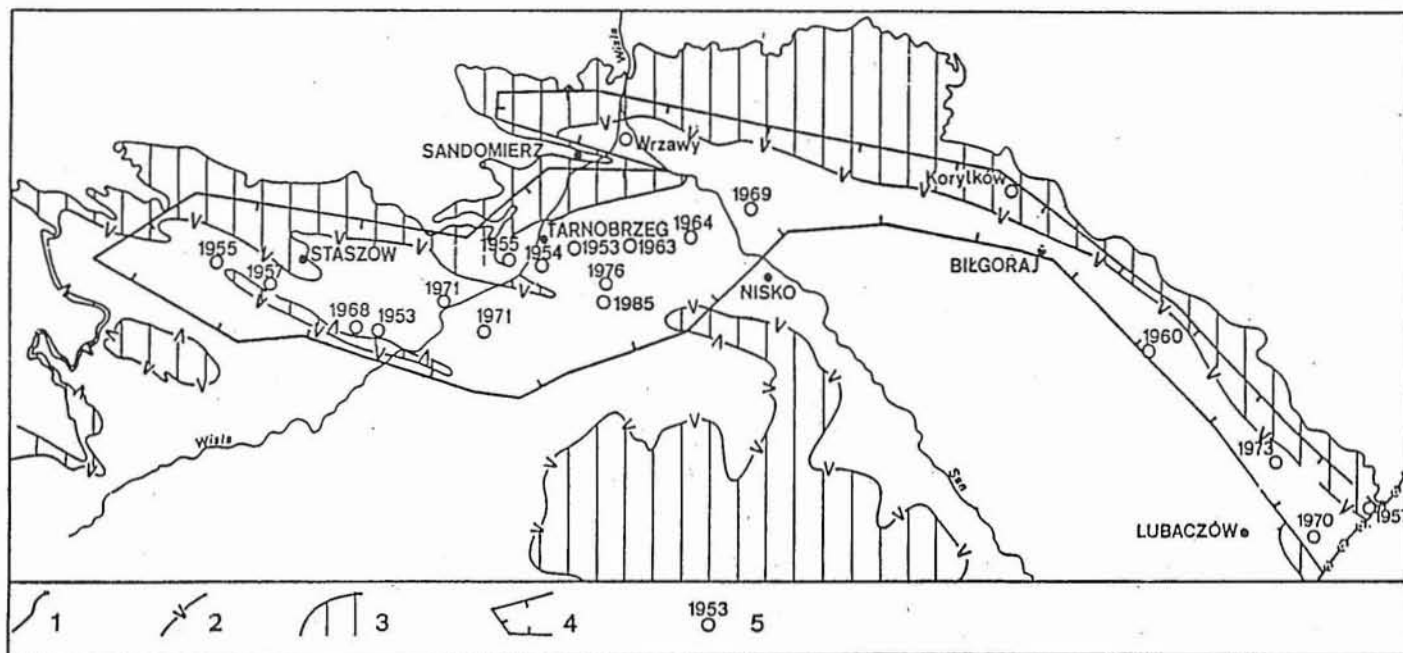


Fig. 3. The area of native sulphur researches in the northern part of the Carpathian Foredeep

1 — northern boundary of the Miocene foredeep, 2 — extent of the sulphate deposits, 3 — sulphate-free area, 4 — the area of researches in 1953–1976, 5 — date of borehole with sulphur deposit finding

Obszar poszukiwań złóż siarki rodzimej w północnej części zapadliska przedkarpacciego

1 — północna granica zapadliska mioceńskiego, 2 — zasięg utworów siarczanowych, 3 — obszary pozbawione siarczanów, 4 — zasięg obszaru objętego poszukiwaniami złóż w latach 1953–1976, 5 — rok wykonania otworu wiertniczego — odkrywczego

managed by J. Borucki from the Geological Institute (presently Polish Geological Institute). The drills were done with various, untypical drilling equipment such as *KAM-500*, *ABWZ*, *UKB*, *SBA-8*, but the core percentage from the ore series was 80–85%, sometimes up to 95%.

The Geological Institute prepared three geological documentations of the Tarnobrzeg – Machów sulphur deposit, as a whole in the C₂ category and of selected areas in C₁ and B categories. The latter two included the results of hydrogeological and of geological-engineering studies. The examined large Tarnobrzeg – Machów sulphur deposit was proposed to be exploited as an open pit. The elaboration of a technical project of an open pit and of processing plants — according to data of geological investigations of the Geological Institute — was carried out by the GOSGORCHIM-PROJECT in Moscow in 1955. Further exploration provided an initial contour of the giant Tarnobrzeg – Machów deposit and the finding of new deposits in Solec near Szydłów (in 1955), in Piaseczno — as a western continuation of the Machów deposit (in 1956) and in Grzybów near Staszów. In all these cases the first boreholes: Machów S-3, Solec E-4, Piaseczno X-14, Gacki 1 and Grzybów 1, drilled sulphur deposit. The discovery of shallow sulphur deposits in Piaseczno (the ore series was situated at a depth of 15 m) and in Solec (at 24 m) enabled the construction of an open pit mine there according to a Polish project. The removal of the overburden began in the first half of 1956 and in December 1957 the sulphur ore was first exploited.

The most significant events during that time were:

- 1955 — March — the discovery of sulphur ore at Solec near Szydłów,
- July — the documentation of the sulphur deposit at Solec,
- December — the finding of the shallow sulphur deposit at Piaseczno;
- 1956 — July — the first strippers worked in the area of the sulphur deposit in Piaseczno,
- August — the documentation of the Piaseczno sulphur deposit;
- 1957 — February — the discovery of a sulphur seam, 31 m thick, at Grzybów near Staszów,
- March — the documentation of the sulphur deposit at Świniary,
- June — The National Planning Committee created a special board for the development of the "sulphuric" region,
- July — the announcement on the sulphur finding at the Trusze village near Horyniec,
- October — the memorandum about further explorations and investigations (by S. Pawłowski),
- December — the sulphur mine in Piaseczno began exploitation.

During 1957–1963 exploration was abandoned, partly due to the improper evaluation of a documented resource base, and also due to false economical decisions, which stated the sulphur industry as being too expensive. The large sulphur resources estimated at that time had to provide all requirements and therefore further explorations seemed to be aimless.

The main purpose of research at that time was the determination of a pattern of sulphur mineralization. General conclusions were:

- sulphur mineralization is connected with elevated structures both of sulphate deposits and of the under-Miocene basement, reflected as gravimetric anomalies,
- this mineralization occurs only within sulphate deposits and it is epigenetic in character.

These assumptions enabled the discovery of new sulphur deposits as well as the prediction of new perspective areas for further exploration. The team of Prof. S. Pawłowski concentrated its research on areas where the thick ore series occurred at depths up to 300 m.

The complex analysis of lithofacies and structural conditions of sulphate deposits in the Carpathian Foredeep eliminated large areas which seemed unpromising. Only 5% (600 km²) of the whole area of 11 000 km² between the Vistula and San rivers, covered with the Miocene sulphate deposits, was established as a perspective area and 2% of the whole was acknowledged as a probably sulphur-bearing.

STUDIES 1963–1976

The next period of studies started with the explanation of resource perspectives and of the possibility of eastward prolongation of this giant Piaseczno – Machów sulphur deposit. The first boreholes: Grębów H-17, Jeziórko F-15 and Jamnica K-19, located a belt of sulphur deposits there in 1964, which tripled the total resources. The eastern end of the Jamnica deposit, continuing between Piaseczno and Rozwadów, was examined in 1971 and parallel field investigations were carried out between the Solec – Gacki deposits and the Grzybów one. The maximum thickness of the ore series, over 40 m, was drilled near Dobrów. In 1968 was documented the Poręba Wierzbicka – Dobrów – Grzybów sulphur deposit and in 1973 — the Rudniki deposit, located on the same geological structure as the Solec – Grzybów deposit. The drills, started in 1969 near Połaniec, confirmed an occurrence of industrial sulphur concentrations there (Luszyca 1 borehole). Also in 1966 on the Dobrów – Grzybów deposit the first underground melting of sulphur was carried out, being the first such experiment in Europe.

At the same time the research was begun on the Horyniec – Basznia region near Lubaczów. The promising results of the boreholes: Trusze 3 and Cieszanów, drilled there in 1957–1960, suggested the presence of sulphur deposits. The structural analysis of this area indicated that a narrow horst was placed between Cieszanów and the national boundary. The Basznia 26 borehole, located on it, found in 1970 rich sulphur deposits and their documentation was officially accepted in 1974. It enlarged the balance of total sulphur resources by 25%. Also the perspective areas and a possible continuation of the Basznia deposit toward Cieszanów were examined. The experimental underground melting mine was opened on the Basznia deposit in 1977.

Parallel exploration drills were realized on the structure between Osiek and Baranów Sandomierski and in 1971 the Łęg 58 borehole located the ore series, 33 m thick, but in the Dymitrów 54 borehole the post-gypsum limestones were found with a thickness of 21 m. During 1973–1976 intensive investigations located in detail and documented the second large sulphur deposit — the Osiek – Baranów Sandomierski deposit. It characterized by a maximum thickness of the ore series, up to 45 m. Its resources enlarged the national balance of sulphur resources by 35%. About 50% of its resources are included within the protecting pillars.

During 1975–1977 the program of exploration of the perspective areas, especially those located southwestward from the Jeziórko – Grębów deposit, was realized. Several boreholes, placed in the Alfredówka – Buda Stalowska region, found gangue and sulphur-bearing limestones with a thickness over 20 m. These works located the southwestern branch of the Jeziórko – Grębów deposit, with approximated resources of 60 mln t. All these studies, done during 1963–1976, enlarged by ten times the base of sulphur resources.

The most important events of this period:

- 1963 — exploration began in the Jeziórko – Grębów region;
 1966 — June — the underground melting sulphur mine was opened at Grzybów, the first in Europe;
 1967 — February — the geological documentation of the Jeziórko – Grębów sulphur deposit,
 — July — the underground melting mine started exploitation at Jeziórko;
 1968 — March — the geological documentation of the Poręba Wierzbicka – Dobrów – Grzybów sulphur deposit,
 — July — intensive field work near Połaniec;
 1969 — the open pit mine was opened in Machów;
 1971 — February — the memorandum about the exploitation and further exploration of sulphur deposits in Poland
 (by S. Pawłowski),
 — March — the geological documentation of the Jamnica sulphur deposit;
 1972 — March — the prognosis of sulphur resources up to the end of the 20th century;
 1973 — June — the valuation of national sulphur resources and the geological documentation of the Rudniki
 deposit;
 1975 — June — the geological documentation of the Basznia sulphur deposit;
 1975 — March — the perspectives of Polish sulphur mining and processing;
 1976 — July — the geological documentation of the Osiek – Baranów Sandomierski deposit;
 1977 — August — the results of geological exploration near Alfredówka,
 — September — the Basznia underground melting mine was opened at Smolinka.

STUDIES 1976–1993

After finishing of the documentation of the Osiek – Baranów Sandomierski deposit the monographies of the two largest sulphur-bearing regions: Tarnobrzeg (S. Pawłowski *et al.*, 1985) and Staszów (in preparation) were elaborated. During 1978–1983 the comparative studies of Polish sulphur deposits with the similar ones in the USA: in Delaware Basin in Texas and in the Mexican Gulf, were carried out, financed by the M. Skłodowska-Curie Fund.

Geological studies in the Alfredówka – Gwoździec region were the last stage of the prospection and documentation of Polish sulphur deposits. They located sulphur-bearing limestones in four drills, with thickness up to 22.3 m (the borehole no. 166). The initial metasomatism of anhydrites and sulphur imprints were found in the Bojanów – Gwoździec region and southward from Dęby an elevated geological structure was detected.

The important events of this period:

- 1976–1984 — the geological monographies of the sulphur-bearing areas: Tarnobrzeg – Jeziórko – Jamnica, Solec – Grzybów, Rudniki and Osiek – Baranów Sandomierski (by S. Pawłowski, K. Pawłowska and B. Kubica),
 1979–1983 — the Polish-American comparative studies, financed by the M. Curie-Skłodowska Fund,
 1984 — the project of geological research in the Alfredówka – Gwoździec region (by K. Pawłowska and B. Kubica),
 1984–1987 — prospecting work in the Alfredówka – Gwoździec region and the final report of studies near Alfredówka, Dęby, Bojanów – Gwoździec areas (by K. Pawłowska and others),
 1992 — the lithofacies characteristics of the Badenian chemical deposits in the northern part of the Carpathian Foredeep (by B. Kubica),
 1993 — the 40th anniversary of the discovery of Polish native sulphur deposits: the scientific conference in Polish Geological Institute in Warsaw on the Tertiary sulphur-bearing formation in the Carpathian Foredeep and the exposition on the history of discoveries and their economical effects.

THE ROLE OF THE GEOLOGICAL INVESTMENTS

All prospecting boreholes were drilled during the period 1953–1976 by the one geological company (actually it is the Drilling and Mining Investment in Kielce). The drills in the Tarnobrzeg – Machów region and part of the research near Piaseczno were done by the Investment of Geological Works from Warsaw. The Geological Investment in Kielce drilled about 440 boreholes with a total length of about 108 km. Also many other geological, hydrogeological and geological-engineering investments, unnamed here, participated in the documentation of resources of C₁–B categories. All the geophysical logs were from the beginning done by the Geophysical Studies Investment from Warsaw. Also should be emphasised here the good cooperation between the researchers from the Geological Institute and the administration of the sulphur mines — for instance, with the first director of the Tarnobrzeg mine ing. F. Machalski, and with the Geologist-in-chief ing. S. Dźwigala.

THE RESEARCH TEAM

All prospecting works, from 1956 up to 1976, were carried out by a small group of geologists from the Geological Institute. This team consisted of a group of constant members (Prof. S. Pawłowski — the leader, M. Sc. K. Pawłowska, Dr. B. Kubica) and of seasonal co-workers, being specialists of hydrogeology, micropalaeontology, geochemistry and others.

IN SUMMARY

The results of the 24-years period of research of sulphur in Poland were as follows:

1. The discovery and documentation of native sulphur deposits created a large resource base for sulphur exploitation and processing.
2. The deep geological structure was recognized over an area of 2000 km². The units of the Miocene sequence from the northern part of the Carpathian Foredeep were characterized and correlated as well as the uppermost Precambrian or lowermost Cambrian, Devonian, Carboniferous and Zechstein deposits were described. Also the uncommon sequence of Triassic sediments was examined in detail and the hitherto unknown Liassic deposits were identified southward from Staszów.
3. The pattern of drillings on the sulphur deposits was invented based on a cross-section method.
4. The preliminary location of the sulphur deposits (Piaseczno, Machów, Jeziórko, Grzybów) was successfully confirmed by further exploitation.

The most (over 80%) of the 569 boreholes, drilled that time, located the sulphur-bearing strata. The total length of all drills was 130 900 m (the length of cores was about 102 km). The total cost of all drills was 156 mln zloty and it equals the actual cost of a one deep borehole (up to the depth 5 km). The circle diagrams (Fig. 4) presents the effects of sulphur

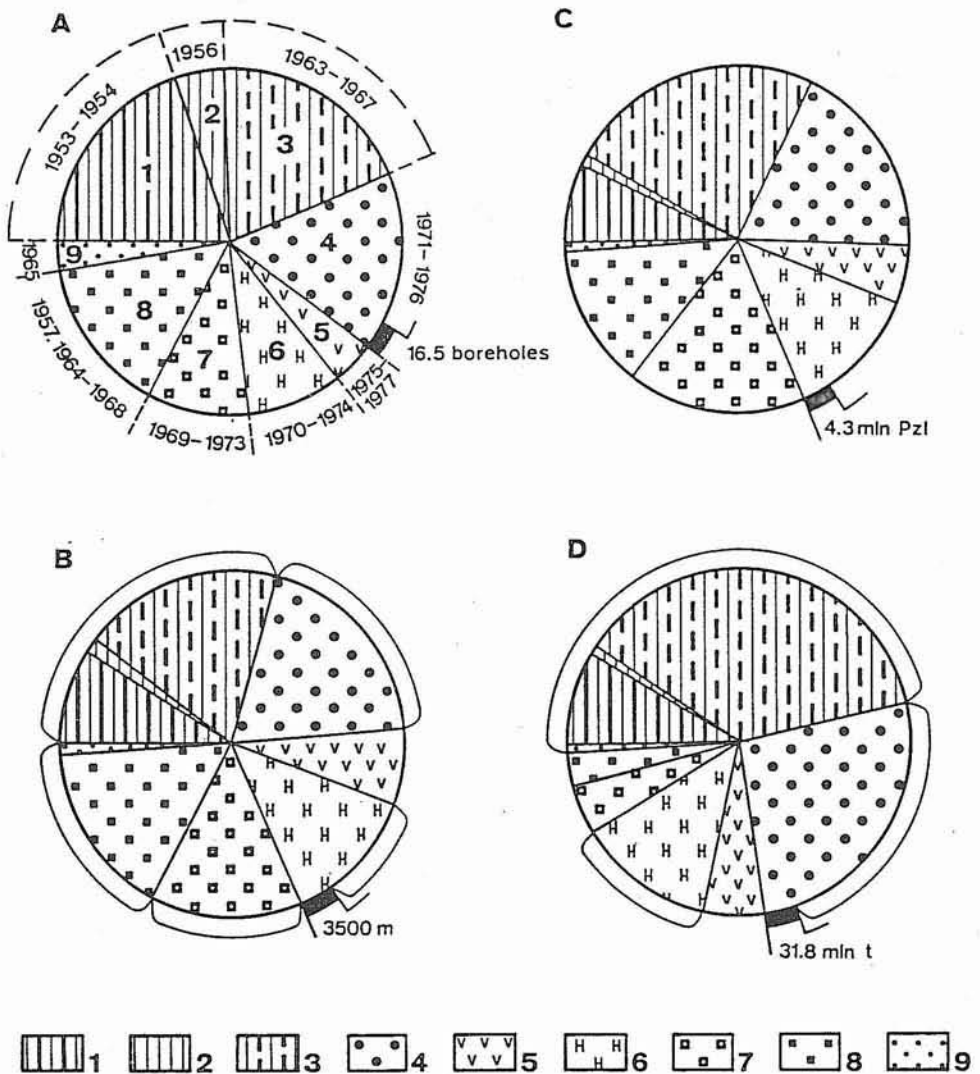


Fig. 4. Circle diagrams of the effects of sulphur research

A — number of boreholes, B — total length of drills, C — total cost of studies, D — documented resources in sulphur deposits; sulphur deposits: 1 — Mokrzyszów — Tarnobrzeg — Machów, 2 — Piaseczno, 3 — Jeziórko — Grębów — Jamnica, 4 — Osiek — Baranów Sandomierski, 5 — Alfredówka perspective area, 6 — Basznia, 7 — Rudniki, 8 — Poręba Wierzbicka — Dobrów — Grzybów, 9 — Solec

Diagramy kołowe podstawowych składników badań

A — liczba otworów, B — liczba wykonanych metrów, C — sumaryczne koszty badań, D — udokumentowane zasoby w złożach siarki; 1-9 — złoża siarki

research (quantity of boreholes, length of drills, costs of exploration, quantity of documented resources within sulphur deposits).

Thus, the period of very intensive prospecting for native sulphur resources in Poland is nearly finished. The ones of the biggest in the world sulphur resources were discovered and documented. The obtained data enable now the ore detail studies on a model of development of Polish sulphur deposits.

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HISTORIA ODKRYCIA NOWYCH ZŁOŻ SIARKI W WIDŁACH WISŁY I SANU (ZAPADLIKO PRZEDKARPACKIE)

Streszczenie

Historię odkrycia złóż siarki w okresie powojennym należy rozpatrywać w pewnym związku z sześciowiekową tradycją górnictwa i przetwórstwa siarki. Dokumenty z czasów jagiellońskich wskazują na dobrze zorgani-

zowany przemysł wydobywczy na przełomie XIV i XV w. Pięciowiekową produkcję siarki z trzech ówczesnych kopalń oszacowano na 200 tys. t, co w konfrontacji z nowym górnictwem siarki stanowiło tylko dwutygodniową produkcję.

W historii poszukiwań i odkryć siarki w Polsce wyróżniamy cztery etapy:

1. Etap rozwoju badań podstawowych i koncepcji poszukiwawczych w latach 1937–1948.
2. Etap realizacji i wstępnych programów badawczych oraz pierwszych odkryć geologicznych w latach 1952–1957.
3. Etap wybitnej intensyfikacji badań i odkryć największych złóż siarki w latach 1963–1976.
4. Etap badań obszarów perspektywicznych, opracowań monograficznych i studiów porównawczych złóż siarki w Polsce i USA (Fundusz M. Skłodowskiej-Curie) oraz sesji naukowej poświęconej 40-tej rocznicy odkrycia złóż siarki w latach 1976–1993.

Niezbadane wglębnie zapadlisko przedkarpackie wypełnione było według ówczesnych poglądów monotonnymi osadami prasarmatu, o grubości od kilkuset do kilku tysięcy metrów i zaburzonych tektonicznie na linii Wisły i Sanu. Taka sytuacja nie zachęcała do poszukiwań. Wykonane przez prof. S. Pawłowskiego badania geofizyczno-grawimetryczne w latach 1937–1939 oraz 1945–1950 ujawniły nieznanne dotychczas anomalie o wyraźnych amplitudach zmienności form w północnej części zapadliska przedkarpackiego. Wskazywały one na odmienne cechy budowy podłoża w różnych częściach obszaru zapadliska. Opracowany na tej podstawie w 1952 r. plan badania struktur, zinterpretowanych geofizycznie przez prof. S. Pawłowskiego, już w pierwszej fazie dał rewelacyjne wyniki: w otworze Luszyca koło Połańca w czerwcu 1953 r. nawiercono wapień osiarkowane (na głęb. 295 m) o grubości 1,5 m. We wrześniu tegoż roku w otworze A-1 w Mokrzeszowie koło Tarnobrzega nawiercono na głęb. 76 m wapień siarkonośny i płytko występujące osady kambru (na głęb. 103 m).

Wyniki tych wierceń miały przełomowe znaczenie dla poszukiwań i odkryć dalszych złóż siarki. W ciągu 24 lat poszukiwań odkryto i udokumentowano 5 złóż siarki rodzimej, w tym 2 z nich: Piaseczno – Machów – Jeziórko – Grębów – Jamnica i Osiek – Baranów Sandomierski, należą do unikatowych w skali światowej.

Ustalona została ogromna baza zasobów siarki — podstawa rozwoju wydobywania i przetwórstwa siarki. O wysiłku małej grupy badawczej świadczy opracowanie ponad 600 otworów poszukiwawczych o łącznym metrażu 130 tys. Koszt tych prac i badań wyniósł 156 mln zł i jest równoważny kosztowi jednego otworu badawczego do 5 tys. m w ówczesnych relacjach cen. Koszt udokumentowania jednej tony siarki wyniósł 15 gr.

W bilansie korzyści należy wymienić znaczący rozwój infrastruktury regionu, powstanie nowoczesnego ośrodka przemysłowego wydobywania i przetwórstwa siarki, będącej podstawowym surowcem chemii oraz przedmiotem międzynarodowej wymiany handlowej.