Mineral resources of the Polish Carpathians and the Carpathian Foredeep and their economic utilisation

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The presented region comprises a south part of Poland. In geologic approach, it belongs to the Carpathian Mountains and the Carpathian Foredeep. There are more than 350 mineral deposits in this region. In the Carpathians there are modest oil and gas deposits, and deposits of common raw materials such as: sand and gravel, clays for brick production and building stones. Some dolomite and bentonite clay deposits are also present. Yet the greatest natural resources in the Carpathians become mineral and thermal waters.

The Carpathian Foredeep is rich in native sulphur and rock salt deposits. It comprises ample natural gas, common clays and limestone and gypsum deposits.

The Carpathian region is a unique part of Poland, because of its environmental value. This fact raises some problems related to exploitation and management of mineral deposits. Some of them are presented in this report.

Key words: *Polish Carpathians, Carpathian Foredeep, mineral resources, mineral waters, natural resources, protection, legislation*

Introduction

Intrinsic economic resources in the Polish Carpathians and their foredeep are the subject of this article.

The Polish part of the Carpathians occupies 18,900 km^2 that is ca 6% of the territory of Poland. This is a specific region and its high environmental value requires a very thoughtful management of natural resources, especially of fossil fuels and groundwater. Large areas of the Carpathians are occupied by protected terrain due to landscape value, conservation of forests, protection of drink-water reservoirs or soils of higher bonitation ranks (Fig. 1).

In the Carpathians there are several types of mineral deposits (Tab. 1), yet only mineral and thermal waters, diatomite deposits as well as building sandstones are important resources in a country scale.

With the Miocene marine sediments of the Carpathian Foredeep are associated main deposits of natural gas, native sulphur (belonging to the largest worlds resources) rock salts, gypsum, limestone for cement industry, building ceramics raw materials and quartzite sands (Tab. 1). Their reserves and an exploitation level are significant in a domestic scale, excluding rock salt whose reserves are significantly limited by an intense exploitation.

Economic value of the remaining resources in the Carpathians and their foredeep is insignificant due to small reserves of some mineral deposits when compared with demands (crude oil) or quality of particular mineral deposits is so low (e.g. diatomaceous rocks, bentonite clays) that potential clients are not interested in their exploitation.

Mineral and thermal waters

According to criteria defined by Polish Geological and Mining Law, mineral resources comprise balneologic waters to which there are included: mineral waters with mineralization not less than 1 g of dissolved substances as well as weakly mineralized waters containing specific components (e.g. CO_2) or those characterized by specific physical properties (e.g. higher temperature). Waters of the temperature exceeding 20°C at their discharge are called thermal. Their reserves are approved by the Ministry of Environmental Protection, Natural Resources and Forestry. Criteria used by the Ministry of Health and Social Affairs for waters possessing therapeutic effects are stricter so only some water resources are recognized as balneologic resources.

Thermal and balneologic waters are the most important resources in the Carpathians. Their proven and exploited

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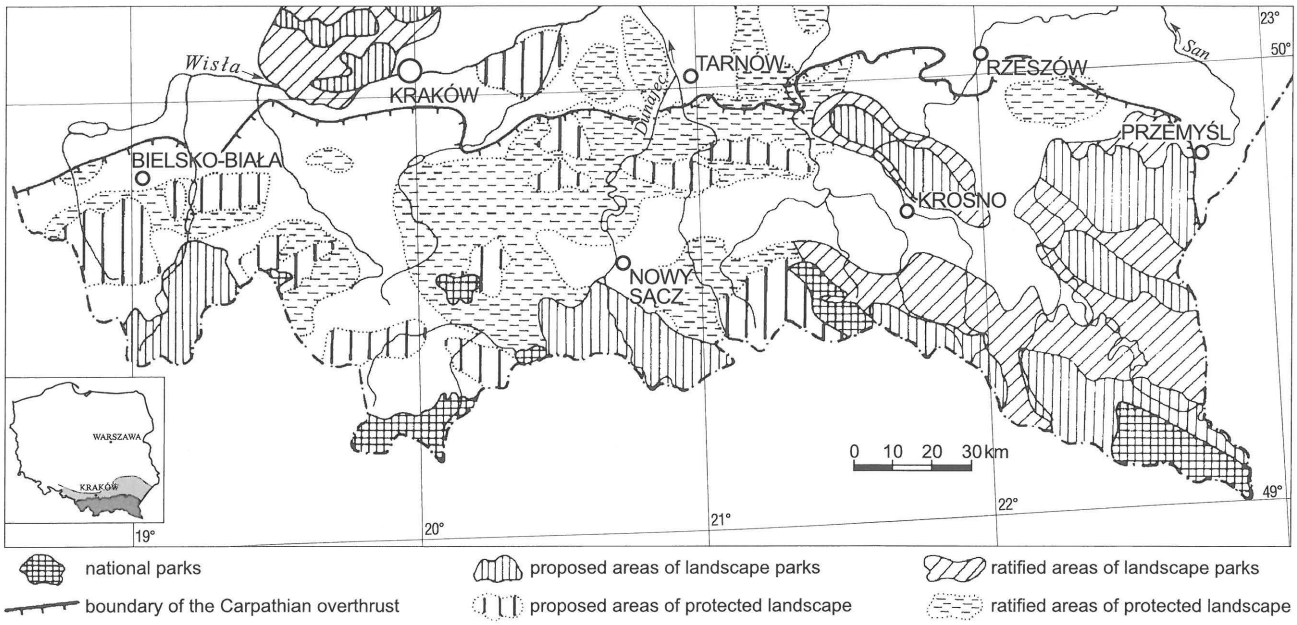


Fig. 1. Landscape protection in the Carpathians (after Czemerda, 1990, partly modified)

reserves amount to 20% of the domestic resources (Fig. 2). Such waters occur in all structural units of the Carpathians (Chowaniec, 1991).

The most characteristic balneologic waters of the Outer Polish Carpathians are chloride waters whose mineralization varies from a few to over 100 g/dm^3, and occurr in flysch sandstones as well as in fractured Miocene and Devonian sediments (the western margin of the Carpathians). Some of these waters are relic ones belonging to the Carpathian province of brines. The discussed waters are utilized in Rabka, Iwonicz and Rymanów Zdrój, while in Sól near Żywiec the waters are drilled yet not exploited.

In the southern part of the Outer Carpathians, i.e. in the regions of Poprad, Iwonicz and Bieszczady, acidic waters (i.e. waters saturated with carbon dioxide) predominate. In majority, the acidic waters are of atmospheric origin, and their carbon dioxide content is related to the Tertiary volcanism. These waters are spread over an extensive area and are utilized by health resorts in Piwniczna, Muszyna, Krynica, Żegiestów. Particularly valuable are complexes of balneologic waters in Krościenko and Szczawnica.

In effect of mixing of acidic carbonate waters with relic brines there are formed unique acidic waters with a higher content of Cl^- ion and mineralization up to 30 g/dm^3. These are so called „zubers" known from the following health resorts Krynica, Muszyna and Złockie. Waters in Wysowa Zdrój are also very unique because of mineralization reaching to 20 g/dm^3 and a higher content of iodine and bromine. Besides the brines and acidic waters, sulphuric waters occur in the Carpathians. Large, yet not utilized resources of mineral waters, namely acidic ones containing arsine, have been proven in Rabe near Baligród (Chowaniec & Poprawa, 1994). Chloride-bromine thermal mineral waters, drilled by Poręba Wielka IG-1 well, are very unusual as well.

In the Inner Carpathians weakly mineralized, thermal waters (mainly sulphide ones) predominate (Fig. 2). Their presence is associated with a deep infiltration of precipitation in the summit parts of the Tatra Mts. Both, Mesozoic sedimentary rocks and the Podhale flysch are water-bearing. They possess over 15% of the domestic reserves of the exploited thermal waters. The temperature of water at its free outlet varies from 22°C (Siwa Woda and Zazadnia boreholes) to over 70°C (Bańska, Furmanowa and Chochołów boreholes).

Until now the proved reserves of the mineral or weakly mineralized waters in the Carpathians, have only been used for therapeutic purposes and as soft drinks. In recent years an interest has focused on thermal waters of the Podhale Basin, where a few years ago utilization of the thermae for heating was initiated. There is also possibility of utilizing the thermal waters for recreation which might contribute to tourist attractiveness of this region.

With the area of the Carpathian Foredeep are associated mainly relic sodium chloride waters with iodine and bromine (Jastrzębie, Goczałkowice) and sulphuric waters related to Miocene evaporites (Swoszowice, Mateczny, Horyniec Zdrój). If these two kinds of waters are in contact, a new mixed type is formed. The exemplification of the latter are waters in Busko and Solec.

Crude oil

In the Carpathians and their foredeep 58 crude oil fields are proven. Its reserves amount to 2.2 million tones which is 15% of the domestic reserves (Tab. 1). The Carpathian oil field occurs mainly in the Silesian Unit, and smaller ones are found in other units (Fig. 3). Structural fields usually predominate while bedded fields are rarer. The Carpathian oil is of methane type and of a high quality. It is light, free from sulphur and either free from paraffin or containing 3.5–7% of the latter (Karnkowski, 1993).

In the Carpathian Foredeep oil fields are mainly of bedded type and occur in Mesozoic sediments (Cretaceous sandstones and Jurassic carbonate rocks) which are underlain by impermeable Miocene clays. The oil in this region is light and medium weight, contains 2.32–9.37% paraffin, and content of sulphur ranges, on the average 0.45–0.85%.

Tab. 1. Measured, indicated and inferred mineral resouces of Carpathians and Carpathian Foredeep (after *Bilans zasobów kopalin i wód podziemnych w Polsce; 31.12.1996 r.*)

Raw material	Quantity of deposits	Intrinsically economic resources	Output 1996 r.	Percent of the country's resources in 1996	Percent of the country's output in 1996
Crude oil — Carpathians	46	1.1 x 10^6 Mg	47.9 x 10^3 Mg	7.6	28.7
— Carpathian Foredeep	12	1.1 x 10^6 Mg	32.8 x 10^3 Mg	7.8	20.2
Natural gas from gas deposits — Carpathians	16	1.3 x 10^9 m^3	38.4 x 106 m^3	1.3	0.7
— Carpathian Foredeep	73	65.0 x 10^9 m^3	1562.0 x 10^6 m^3	48.9	35.6
— connected with crude oil — Carpathians	26	0.2 x 10^9 m^3	6.1 x 106 m3	<1	<1
— Carpathian Foredeep	7	0.3 x 10^9 m^3	6.6 x 10^6 m^3	<1	<1
Rock salt	5	4371 x 10^6 Mg	55 x 10^3 Mg	5.4	2
Native sulphur*	13	513.6 x 10^6 Mg	1.8 x 10^6 Mg	>99	100
Gypsum	10	17.66 x 10^6 Mg	0.7 x 10^6 Mg	54.0	80
Diatomaceous rock	3	10 x 10^6 Mg	2 x 10^3 Mg	100.0	100.0
Building and road stones:					
Carpathians — sandstones	90	999 x 10^6 Mg	1.2 x 10^6 Mg	13.0	6.8
— limestones	2	5.8 x 10^6 Mg	0.1 x 10^6 Mg	<1	<1
Carpathian Foredeep — limestones	36	726.6 x 10^6 Mg	0.9 x 10^6 Mg	9.0	5.0
Limestones and marls for the cement industry	7	1512 x 10^6 Mg	2.6 x 10^6 Mg	12.8	12.5
Limestones and marls for the lime industry	10	535 x 10^6 Mg	–	10	–
Natural aggregates**	103	1033 x 10^6 Mg	2401 x 10^3 Mg	8.1	5.5
Foundry sands	1	15.5 x 10^6 Mg	–	4.3	–
Glass sands	4	9.4 x 10^6 Mg	73 x 10^3 t	2	7
Quartz sands for production of cellular concrete	6	7.8 x 10^6 m^3	44 x 10^3 m^3	5.8	7.3
Quartz sands for production of lime-sand brick	10	24.7 x 10^6 m^3	71 x 10^3 m^3	9.1	6.5
Ceramic clays — Carpathians	65	63.9 x 10^6 m^3	140 x 10^3 m^3	3.1	4
— Carpathian Foredeep	228	370.2 x 10^6 m^3	500 x 10^3 m^3	19.5	16
Clay for lightweight aggregate production	4	23.3 x 10^6 m^3	–	12.2	–
Clay for cement production	3	71.5 x 10^6 Mg	–	28.8	–
Bentonitic clays	4	1.1 x 10^6 Mg	–	28.1	–
Mineral waters*** — Carpathian Foredeep		120.4 m^3/h	li	3.4	
— Inner Carpathians		377.7 m^3/h	li	10.5	
— Outer Carpathians		297.0 m^3/h	li	8.3	
Thermal waters — Inner Carpathians		62.2 m^3/h	li	2.8	
— Outer Carpathians		252.0 m^3/h	li	11.5	

* — mineable reserves
** — natural aggregates of the Carpathians and connected with the Carpathian rivers
*** — together with the thermal waters
li — lack of information

The economic values of the crude oil resources in Poland are not very intrinsic because the total proved resources correspond only to a half year country's demand on it, and exploitation of an order of 150,000–160,000 tonnes (including 80,000 from the discussed region), amounts to less than 1% of a yearly country's demand. Proved resources of Southern Poland are almost used up and almost fully managed, thus any increase in exploitation would require a discovery and management of new fields. Unfortunately, prospecting in this field is not very encouraging, yet some optimists might be encountered.

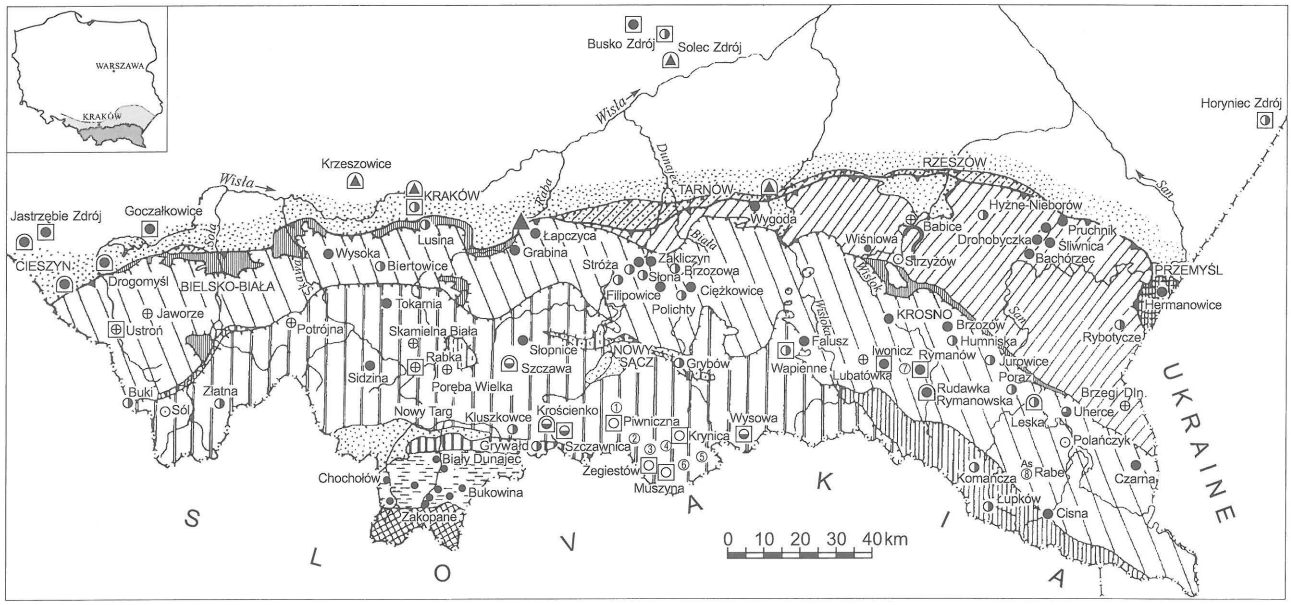
Natural gas

Both exploration and prospecting reserves of natural gas occurring in the Carpathian Foredeep and in a smaller amount in the Carpathians come to 67x10^9 m^3 (Tab. 1). The gas output covers ca 17.5% of a yearly country's demand. As it was the case of the crude oil, the gas fields are intensely managed (in 82%) and have been exploited for many years at the same level (Radwanek-Bąk, 1994). Thus, any increase in a natural gas yield is possible if new fields are disovered and indicated.

In the Carpathians, gas occurs in Cretaceous and Triassic rocks while in the Carpathian Foredeep, the gas fields are in Jurassic, Cretaceous and Miocene sediments. These are structural-lithologic, multi-bedded fields under gas-pressure conditions. The gas of the discussed fields has a high methane and low nitrogen content.

Rock salt

In the Carpathian region rock salt deposits are associated with Miocene marine sediments of the foredeep. Except for one autochthonous bed in Rybnik–Żory–Orzesze, which is located in the western part of the foredeep, the remaining deposits are in a near-Carpathian belt between Kraków and Tarnów (Fig. 4). These deposits were formed due to secondary enrichment of salt series which was later subject to tectonic deformation. Salt mining in this region ceases (Tab. 1). The salt-bearing formations in Wieliczka and Bochnia have been exploited since the Medieval and their reserves are mianly depleted. Small amount of brine are obtained from deposits in Barycz and Wieliczka. The salt deposit Siedlec–Moszczenica after a short exploitation has



Structural units:
- Tatras
- Podhale Basin
- Pieniny Klippen Belt
- Magura Unit
- Fore-Magura Scale
- Dukla-Grybów Unit in the tectonic windows of the Magura Unit
- Dukla Folds
- Silesian Unit
- Sub-Silesian Unit
- Skole Unit
- unfolded Miocene from the Carpathian and the Carpathian Foredeep
- folded Miocene in the marginal zone of the Outer (flysch) Carpathian overthrust
- Stebnik Unit
- rim of the Carpathian overthrust
- overthrust boundary of the Carpathian main tectonic units

- thermal waters in the Podhale Basin and Strzyżów Depression
- therapeutic thermal waters outside the health resorts
- therapeutic thermal waters in the health resorts
- non therapeutic thermal waters
- health resorts with HCO_3-Ca waters
- health resorts with HCO_3-Cl-Na, Br, J waters of differenciated mineralization
- acidic waters exploited in settlements without a health resorts status
- other sites with acidic waters (1 – Głębokie, 2 – Łomnica, 3 – Wierchomla, 4 – Złockie, 5 – Tylicz, 6 – Powroźnik, 7 – Rymanów, 8 – Rabe [As waters])
- therapeutic sulphuric waters in the health resorts
- other therapeutic sulphuric waters
- other sulphuric waters
- former exploited mineral waters
- Cl-HCO_3-Na, J, Br waters in health resorts
- therapeutic Cl-Na waters
- other Cl-Na waters
- brine exploitation for jodine production
- sulphate and other waters

Fig. 2. Mineral and thermal waters in the Carpathians and the Carpathian Foreland against a background of geological structures (after Chowaniec & Poprawa, 1994)

been converted in an underground reservoir of natural gas. There are still large reserves in the deposits in Wojnicz (near Tarnów) and Rybnik–Żory–Orzesze. However, these deposits are not intrinsically economic because of immense resources and sufficient yield of the rock salt from Permian diapir deposits of Central Poland.

Native sulphur

The deposits of native sulphur occurring in Poland (Tab. 1) are related to Badenian marine deposits of the Carpathian Foredeep and occur mainly in gypsum-related limestones. Sulphur fills up small caverns and chaps, and its content in the rock reaches on the average 15–30%. The sulphur concentrations of industrial importance are present in elevated structures formed during the tectonic rebuild of the foredeep in the Badenian. The sulphur-bearing formations are clustered in the northern part of the foredeep, where 5 regions are identified: Tarnobrzeg, Staszów, Osiek–Baranów, Rudniki, Lubaczów (Fig. 4). There are 3 deposits currently exploited: Jeziórko–Grzybów–Wydrza, Grzybów–Gacki and Osiek (since 1993), all by the borehole mining method. In 1993 exploitation of Basznia deposit (Lubaczów region) was discontinued and open-pit mining of Machów bed has been finished.

Gypsum

Large gypsum deposits (over 50% of Polish indicated and inferred mineral resources — Tab. 1 — occur in Miocene of the Carpathian Foredeep — in the Nida valley, at the southern outskirt of the Holy Cross Mts — Fig. 4). Gypsum occurs here in the considerable area just under the ground surface or under an insubstantial overburden (1.5–15 m). Thickness of gypsum varies from 10 to 46 m. Currenty exploited are deposits Borków–Chwałowice and Leszcze. Minor gypsum deposits are also known from the area of the Carpathians. The bed of alabaster gypsum in Łopuszka Wielka between Rzeszów and Przemyśl is a peculiarity in a country's scale. In the past it was used as decorative stone and sculpture material. After digging out the best fragments of the bed, exploitation was quited, yet recently there have been attempts to undertake it again.

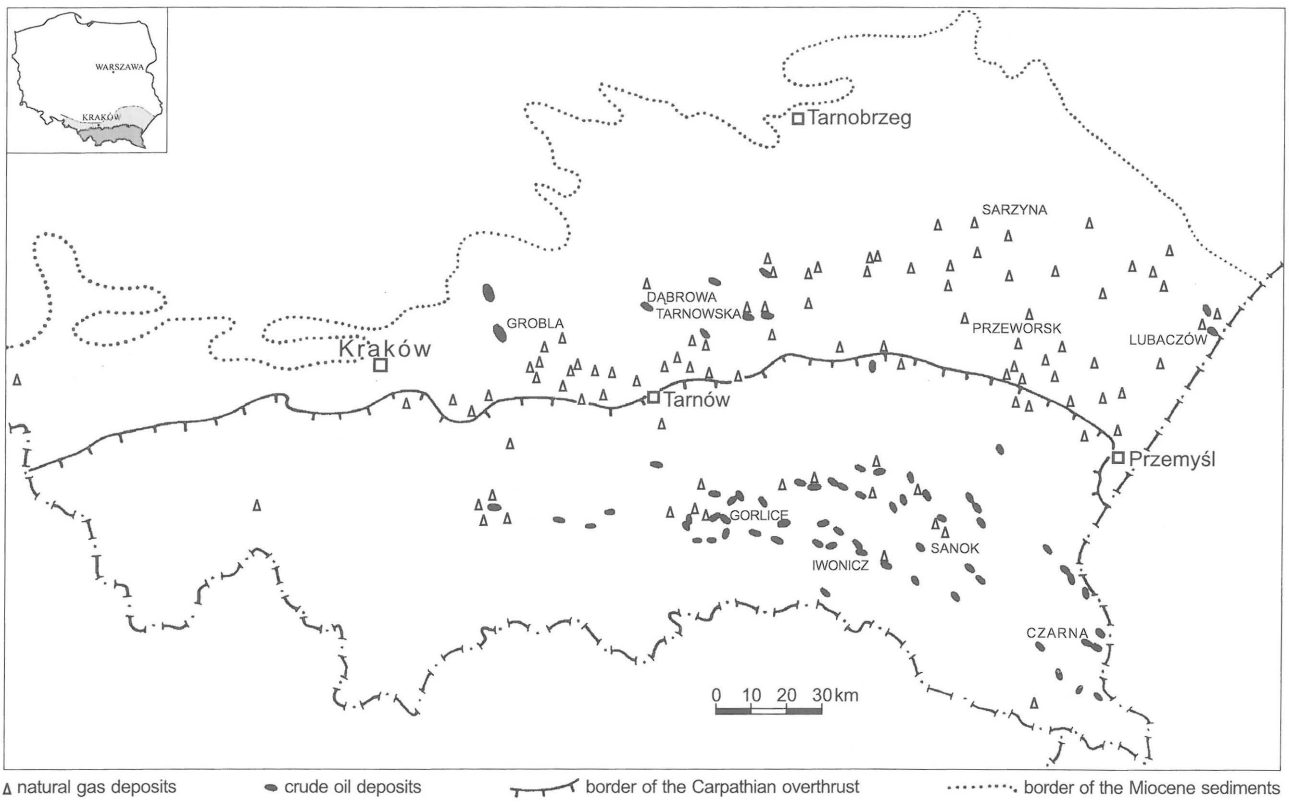


Fig. 3. Crude oil and natural gas deposits in the Carpathians and the Carpathian Foredeep (after Karnkowski, 1993)

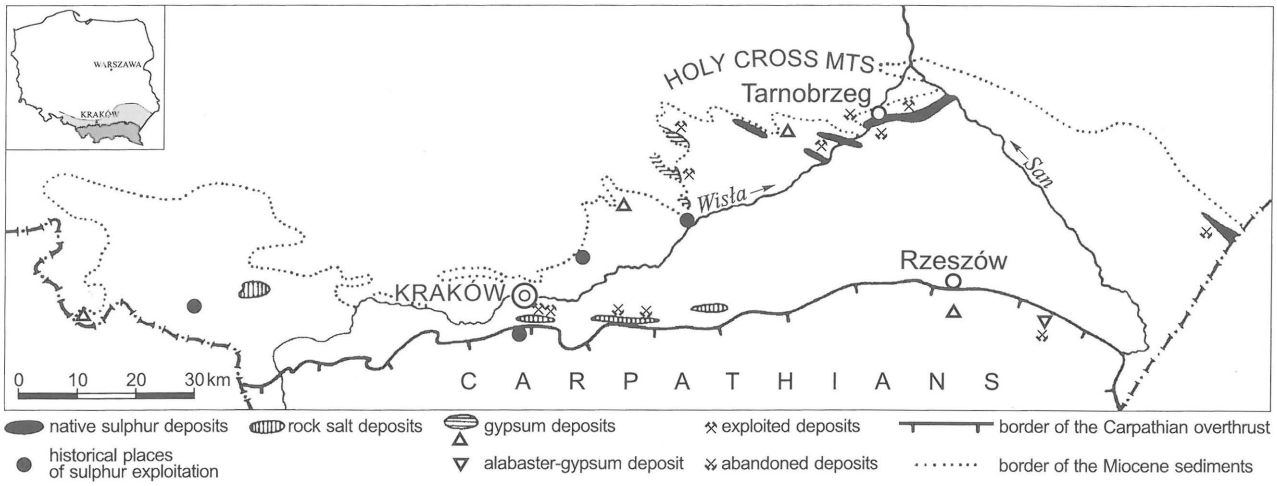


Fig. 4. Mineral deposits of native sulphur, rock salt and gypsum in the Carpathians and the Carpathian Foredeep

Building and road stones

Among various rock materials used as building and road stones in the Carpathians only sandstones are widely utilized. For building purposes limestone is exploited in some locations, for example in vicinity of Cieszyn and Żywiec. Other rocks such as granite, limestone and dolomite (the Tatras) or limestone and dolomite (the Pieniny Mts) occur in a terrain which is excluded from management, in areas of national parks. In the Carpathian Foredeep, there are deposits of Tertiary limestone, exploited both as building and road stones as well as a raw material for cement and limestone industry.

The intrinsically economic resources of the Carpathian sandstones amount to 74% of all sandstones in Poland, and to about 13% of the countrys resources of building and road stones (Tab. 1). The majority of the Carpathian deposits have a small magnitude — in 40% of them the resources are less than 10^6 tonnes, and only in 1% it is over 100 million tonnes (Radwanek-Bąk, 1996).

About 34% of deposits is under management, including 13% abandoned ones. In 1996 twenty eight deposits were under exploitation, yet over a half was managed in a small scale. Over 65% of the resources (mainly inferred resources) is in the deposits that have not been exploited yet and constitute a resource reserve.

The Carpathian sandstones differ significantly with respect to appearance and quality, as well as show a significant diversity in particular beds. They occur in all structural units (Fig. 2), yet from exploitation point of view the most impor-

tant are Krosno Sandstones, Magura Sandstone of muskovite facies, Godula Sandstone and Cergowa Sandstone (Peszat, red. 1976a, Peszat 1976b; Bromowicz 1993).

Among the Carpathian sandstones, only a small part has the properties which cause this raw material to be suitable for production of block stones, plates and geometric elements. The largest accumulation of such deposits is in the part farthest to the west, in Bielsko voivodeship (administration unit), mainly in vicinity of Brenna and Wadowice (Bąk & Radwanek-Bąk, 1996). In the Carpathians there are almost 30 sandstone deposits having weaker or stronger properties of block stones.

The most widely spread are so called Krosno Sandstones that occur in the Silesian, Skole, Dukla and Fore-Magura Unit (Fig. 2). Their qualitative properties vary in a wide range. These sandstones are used as building and road material and sometimes as high quality block (Górka Mucharz).

The Magura Sandstones of muskovite facies form a significant part of the Magura Unit outcrop, including main ridges of the Beskidy Mts. They are usually thick-bedded sandstones with shale intercalations and their qualitative parameters are rather stable. This raw material is mainly used in road building (e.g. quarries in Wierchomla, Tenczyn Górny, Męcina, Klikuszowa). A smaller spatial spread and higher inhomogenity in technical parameters are typical of the Magura Sandstone of muskovite facies.

The Godula Sandstones are mainly developed in the western part of the Silesian Unit. They are characterized by very high quality, therefore they have been used for building (e.g. Głębiec) and road construction (e.g. Obłaziec–Gahura) for many, many years.

The Istebna Sandstones (Sobolów near Bochnia, Wola Komborska near Krosno) are also used as block stones.

The occurrence of the Cergowa Sandstones is limited to the Dukla Unit. These sandstones are developed in facies of normal flysch with complexes of thick-bedded sandstones. They are characterized by a significant lithologic variability. These sandstones are utilized in road building while they are extraced in quarries Lipowica II and Klęczany (the largest quarry in Poland).

In the area of the Carpathian Foredeep the deposits of building stones have been indicated and measured in the Badenian lithotamnia limestones and in the Sarmatian organodetritic limestones. Most of these limestones have properties of block stones which together with other favourable qualitative properties and treatment feasibility make these limestones a neded building material. Limestones from the deposits in Pińczów, vicinity of Busko Zdrój, Staszów, Chmielnik, Szydłów are most famous. In the eastern part of the foredeep, in Roztocze Upland — Zamość region, limestone is currently exploited from deposits in Babia Dolina (Józefów), Żelebsko and Brusno near Horyniec Zdrój.

Limestones for cement and lime industries

Limestones for cement and lime industries occur almost exclusively in the region of the Carpathian Foredeep, in its northern and eastern parts. Marls and marl-detritus lithotamnia limestones (deposits in Płazów, Potok, Frampol) are mainly used in cement industry. Their indicated and inferred resources amount to almost 13% of the countrys resources and provide over 12% of the domestic production. For lime industry suitable are serpula limestones that are characterized by a high content of CaO and high resistance to compression (e.g. deposits in Łysaków, Gliniany–Stróża, Nowiny Horynieckie). They are not exploited at present.

The Carpathian limestones and marls of Lower Cretaceous and Upper Jurassic, so called Cieszynian Limestones, which were exploited in the past are now of historical value only.

Ceramic clays

Among building ceramic clays of the Carpathians and their foredeep, the deposits of the latter are much more important (Tab. 1). In these regions there are several types of raw materials: flysch clay-slates, Miocene clays, Quaternary till and clay, fluvial sandy silts, loess-like clay and clayey-sandy loess.

Miocene marine clays occur mainly in the Carpathian Foredeep, where they are known as Krakowiec Clays of Sarmatian age. They are widely spread, reach a significant thickness and usually have good quality (Wyrwicka & Wyrwicki, 1994). The major deposits occur in vicinity of Tarnów (Wola Rzędzińska), Kraków, Rzeszów and Kolbuszowa. Grabowiec and Chodenice clays, in places cropping out along the Carpathian margin, are slightly older, of the Tortonian. The Tortonian clays are also known from the Upper Silesian Coal Basin.

The Miocene clays occur also in the area of the Carpathians, e.g. in Nowy Sącz, where there are large deposits (e.g. Biegonice–Dąbrówka, Bielowice) and some brickyards.

Flysch clay-slates occur mainly in the Krosno Beds, e.g. in vicinity of Biecz, Jasło and Krosno, more rarely in clay-slates of Eocene and Cretaceous (e.g. in surroundings of Gorlice). These deposits are strongly folded, tectonically deformed, their thickness varies from a few to several meters and are often interbedded with sandstones.

Quaternary tills and clays have small thicknesses and differ as to lithology, and are mainly used for brick production. They form either individual modest fields or co-occur with the raw materials described above, being then a thinning material.

Natural aggregates

The Carpathians and their foredeep are rich in natural aggregates (over 17% of intrinsically economic domestic resources, Tab. 1). Here, gravel and sand-gravel aggregate of fluvial origin predominate that are associated with low terraces. Sandstone gravels, occurring in the Upper Wisła, Soła, Skawa and Raba valleys and in the upper reaches of rivers and streams flowing east of the Dunajec river, prevail. In the east, in the valleys of Biała, Wisłoka and San rivers, sandstone gravels with admixture of menilite cherts prevail while in the rivers and streams draining the Tatras (Dunajec, Białka, Poprad) sandstone-granite-quarzite gravels are predominant. To the north of the Carpathian region the deposits are characterized by a higher content of sand. In the alluvial deposits, the sands usually build the upper, near-the-surface layer of the natural aggregates, yet their content decreases downward. In the terrain which was under South Polish Glaciation Mindel deposits of fluvioglacial and dune sands form individual bodies. In natural aggregates a tiny admixture of material dragged from the north is observed.

Diatomaceous rock

In Poland as yet no typical diatomite deposits have been discovered. However the rock which is characterized by a silica content of 72%, apparent density of 1.42 g/cm^3, bulk density of 0.5–1.28 g/cm^3 and porosity of 28.5%, i.e. by parameters much different from those of typical diatomaceous rock, is known. This an exclusive Carpathian raw material and occurs in the menilite series of the Krosno Beds. The magnitude of intrinsically economic resources is more than 10 million tonnes. The diatomaceous rocks cluster in three deposits in Przemyśl voivodeship. Currently, exploitation in a small scale is in Jawornik deposit while in the others it is stopped. Diatomites are a deficit raw material in Poland, yet a minor utilization of a domestic material is related to its low quality and necessity of enrichment. The applied technology do not guarantee obtaining a product of a satisfactory trading value.

The remaining raw materials (quartz sands for production of cellular concrete and lime-sand brick, glass sands, foundry sands and clay raw material for cement industry and for leightweight aggregate production) form only singular deposits in this region (Tab. 1), constitute a minor part of the domestic resources and their exploitation is not intrinsically economic.

This short overview presents the current state of the mineral industry in the Carpathians and their foreland while the number of inferred mineral resources which have not come into exploration yet points to possible development of this industry in the nearest years. These possibilities are limited because of environment protection and progressing build-up.

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