

Helium deposits in Poland: exploration, discovery and resource potential in the light of the EU Critical Raw Materials Act (CRMA)

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Abstract. Helium, together with lithium and hydrogen, is an important element supporting the energy transition and the global economy in pursuit of a “zero-emission system”. Helium has been recently reintroduced into the list of critical raw materials [Regulation (EU) 2024 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials]. Since reintroduction, EU Member States have been obliged to assess their geological knowledge on helium resource potential and develop strategies aimed at discovering and evaluating new helium resources. We overview the helium geological resources of Poland, outlining the importance and size of geological resources as helium begins to play a significant role in the raw materials policy of many world economies. This article focuses on ⁴He, the most abundant stable isotope of helium on Earth. Global demand for helium and its price are growing along with economic development.

Keywords: helium resources, helium production, helium deposits, helium recovery technology, prospective areas

INTRODUCTION

Helium, a chemically inert gas, was discovered in 1868 by P.J.C. Janssen and J.N. Lockyer by analysing the chromatosphere spectrum of a solar eclipse. It is the second (after hydrogen) most common element in the universe.

Two stable isotopes of helium occur in nature: ³He and ⁴He, differing in the number of neutrons in their nucleus. ³He has two protons and a neutron, while ⁴He has two protons and two neutrons. The basic isotope of helium is the isotope ⁴He (the isotope ³He constitutes only 0.000137% of He on Earth). ⁴He has specific physical and chemical properties which are unique (see Table 1), such as the lack of a triple point on an equilibrium phase diagram and achieving a superfluid state at a temperature of 2.17°K characterized by superconductivity, negligible viscosity and very high thermal conductivity (1,000 times higher than copper). Because of these properties, helium has various applications

in modern economy, being used in medical research, semiconductor production, space exploration, fiber optics and the generation of nuclear power.

HELIUM RESOURCES IN POLAND AND WORLDWIDE

Global resources of helium, evaluated as an associated gas in natural gas fields and in oil fields with a gas cap, are estimated at ~40 billion cubic metres (Goodin, 2024).

The largest known helium resources are located in Qatar (10.1 billion cubic metres) and the United States [8.54 billion cubic metres (8,490 million cubic metres resources and 51.5 million cubic metres reserves)] constitute almost 50% of the total world resources (Table 2).

Poland ranks seventh in the world in terms of amount of helium resources with almost 24 million cubic metres of proved reserves. It is also the only producer of helium in Europe.

Table 1. Properties of ⁴He (Tomasz, 1978)

Parameter	Value
Density	0.17847 kg/m ³
Density in a liquid state	124.9 kg/m ³ , normal pressure, temp. 4.215°K
Density in a solid state	361 kg/m ³
Dynamic viscosity	1.88 × 10 ⁻⁵ Pa × s
Thermal conductivity coefficient	0.144 W/(m × °K)
Helium solubility in water	9.7 cm ³ /kg (normal conditions), – 8.61 cm ³ /kg (293°C, 0.101 MPa), 8.42 cm ³ /kg (303°C, 0.101 MPa)
Boiling point (condensation)	4.215°K
Melting point at a pressure of 3 MPa	1.78°K
Specific heat at a constant pressure	5.275 J/(g × °K)
Specific heat at a constant volume	3.128 J/(g × °K)

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Table 2. Helium resources in the world (Goodin, 2024; Czapigo-Czapla, Brzeziński, 2024)

Country	Helium resources [bcm]	Helium production [mcm]
Qatar	10.1	66
United States	8.54	79
Algeria	8.2	10
Russia	6.8	8
Canada	2.0	4
China	1.1	–
Poland	0.023	2.63

Since 1964, when helium resources were first evaluated in Poland (the Goczałkowice-Dębina deposit in the Upper Silesian Coal Basin) the same methodology for evaluating helium has been used. According to law (Regulation of the Minister of the Environment of 1 July 2015 on the geological and investment report of a hydrocarbon deposit),

a minimum average helium content in natural gas of 0.2% vol. obliges the user of a natural gas field to evaluate its resources of helium. So far, helium resources have been identified in 21 natural gas fields (Table 3).

As of December 31, 2023, helium resources have been evaluated in 17 natural gas fields, amounting to nearly 24 million cubic metres (Czapigo-Czapla, Brzeziński, 2024). Helium, which occurs together with natural gas, is predominantly trapped within the Rotliegend, Zechstein Limestones, and Main Dolomite formations, with the exception of the Trzebusz deposit where the gas is stored in Carboniferous sandstones. Natural gas, in which helium has accumulated, is methane-nitrogen gas, free of the hydrogen sulphide and gasoline fractions.

All natural gas fields with an evaluated helium content (except for the Trzebusz deposit), are located in the Zielona Góra-Rawicz-Odolanów area within the Wielkopolska petroleum province (Fig. 1).

Natural gas fields that meet the minimum helium content criteria occur not only in the Wielkopolska petroleum province, but also in the Małopolska and Pomorze petroleum provinces. However, the helium resources in these deposits have not been evaluated.

Table 3. Natural gas fields in Poland with evaluated helium resources

No.	Name of the deposit	State of development	Extractable helium resources as at 31.12.2023 [mcm]	Helium extraction in 2023 [mcm]	Methane content [% vol.]	Helium content [% vol.]
1.	Bogdaj-Uciechów	E	10.20	0.22	54.5422	0.4101
2.	Brzostowo	Z	—	—	64.2065	0.3211
3.	Ciechnowo	Z	—	—	47.672	0.161
4.	Czeszów	E	0.90	0.000029	63.90	0.27
5.	Dębina	R	0.29	—	30.61	0.2163
6.	Goczałkowice-Dębina	Z	—	—	?	0.38
7.	Góra	E	0.30	0.06	45.9182	0.2342
8.	Grabówka E	Z	0.08	–	59.8130	0.2452
9.	Grochowice	E	1.99	0.10	34.60	0.31
10.	Kandlewo	R	0.47	—	24.29	0.26
11.	Kulów	R	0.05	—	33.14	0.2296
12.	Naratów	E	0.16	0.02	46.64	0.23
13.	Niechlów	E	0.03	0.02	40.64	0.26
14.	Pakosław	R	1.00	—	52.1088	0.4094
15.	Ślubów	E	0.24	0.02	62.1840	0.2290
16.	Tarchały (d.g.+cz.s.)	E	4.06	0.08	59.140	0.375
17.	Trzebusz*	E	1.43	0.01	45.22	0.25
18.	Wierzchowice	Z	—	—	68.9913	0.3048
19.	Wilcze-czerw. spąg.	R	1.52	—	23.10	0.2514
20.	Wilków	E	1.13	0.11	37.68	0.25
21.	Wysocko Małe E	E	0.11	0.000765	66.80	0.27

* in the Trzebusz field, helium resources of 2.5 million m³ were reported in 2019 (Czajka, 2019), while the operator of the gas field withheld information about the extraction of helium from natural gas in Amendment No. 1 to the Trzebusz field report of 2021 (Czajka, 2021).

Explanations: **E** – exploited deposit; **R** – deposit with resources assessed in detail; **Z** – abandoned deposit, **d.g.+cz.s.** – Main Dolomite+Rotliegend

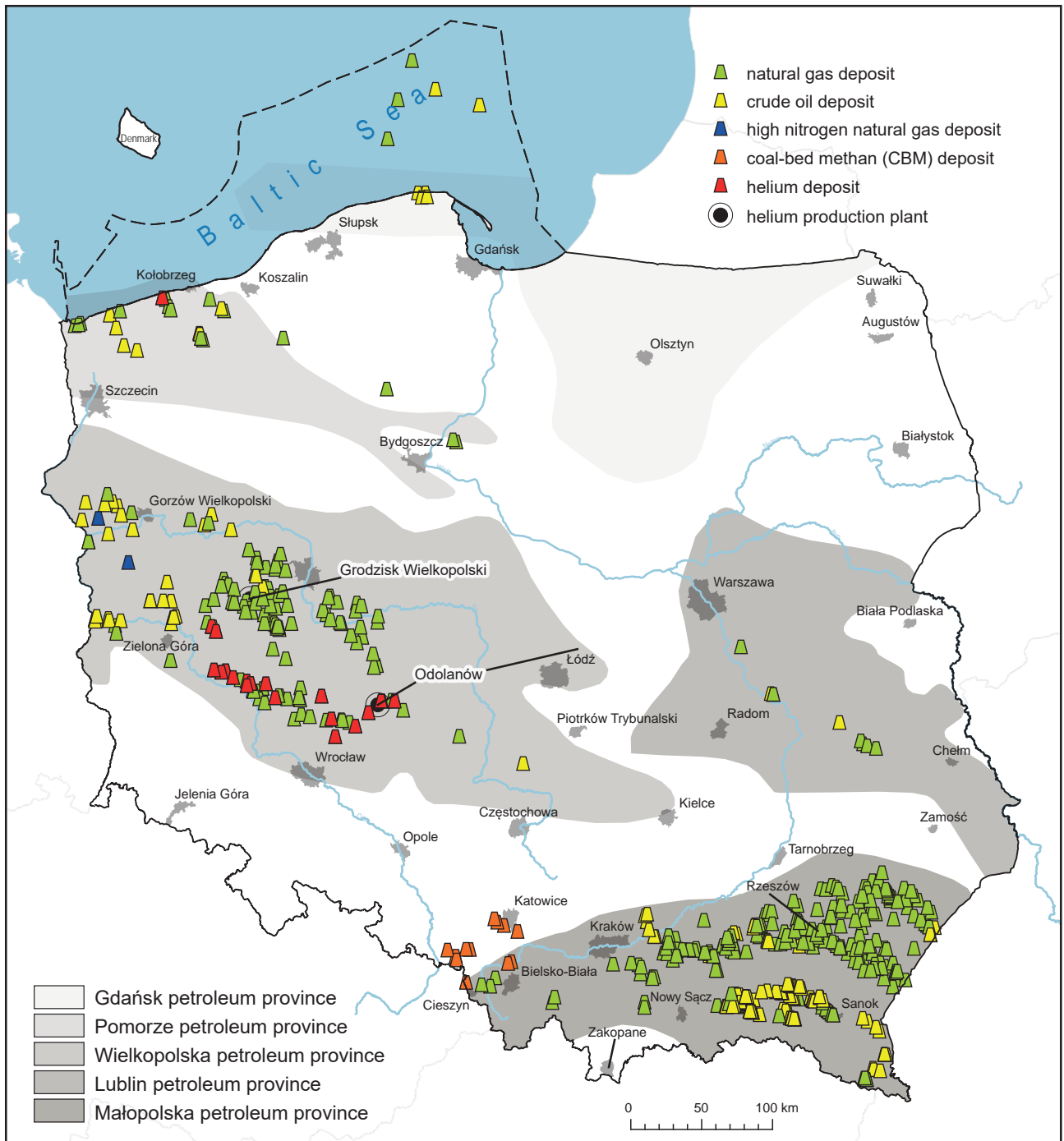


Fig. 1. Location of hydrocarbon deposits in the petroleum provinces (Karnkowski, 1997)

HELIUM PRODUCTION IN POLAND AND WORLDWIDE

Helium production, being a minor by-product of natural gas production, amounted to 171 million cubic metres in 2023 (Goodin, 2024), of which the United States produced 79 million cubic metres of helium (60 million cubic metres were extracted from natural gas, and an additional 19 million cubic metres came from the Cliffside field's reserves in Texas). Qatar, supplying mostly Asian markets, is close behind the United States, with a total production of 66 million cubic metres of helium in 2023 (Table 2).

In the United States, the majority of helium production comes from the Hugoton-Panhandle gas field with an aver-

age helium content of 0.63% vol. (Wingerter, 1968; Beams, 1982; Dubois *et al.*, 2006; Halford, 2018; Lang *et al.*, 2024). In Qatar, the main helium production comes from the North Dome gas field, where the average helium content is 0.04% vol. (Gluyas, Fowler, 2024).

Other major producers, such as Algeria, Poland and Russia – supplying mostly European markets – provide for 12% of helium global supplies (Table 2).

Poland is a pioneer in helium production in Europe. Since 50 years, helium has been separated in Poland in a dedicated facility at Odolanów. The helium separation installation in Odolanów was the first installation outside the United States and the fourth in the world.

Over the last 50 years the ORLEN S.A. – PGNiG Odolanów Branch has produced ~105 million cubic metres of helium (Czapigo-Czapla, Brzeziński, 2024). The annual extraction of pure helium in the ORLEN S.A. – PGNiG Odolanów Branch is almost 3 million cubic metres, whereas according to data published in the “Summary of mineral deposit resources in Poland as of 31.12.2023”, helium production amounted to 0.64 million cubic metres in 2023.

The discrepancy in the reported data is due to the fact that in the “Summary of mineral deposit resources in Poland as of 31.12.2023”, the helium production volume is provided only for natural gas fields with evaluated helium resources.

The ORLEN S.A. – PGNiG Odolanów Branch, by carrying out the nitrogen separation necessary before gas injection into the network, also produces helium from natural gas supplied to the denitrification plant.

Therefore, helium is actually produced from natural gas fields where:

- the minimum helium content in the natural gas field is 0.2% vol.;
- the minimum helium content in natural gas field is <0.2% vol., though due to gas denitrification, helium is also recovered.

HELIUM RECOVERY TECHNOLOGY

Helium extraction depends not only on the presence of helium-rich gas fields but also on the availability of the expensive infrastructure required.

Until recently, commercial helium production was achievable through one of two methods:

- low- and high-pressure systems;
- low-temperature liquefaction.

The low- and high-pressure method involves initial processing of natural gas to remove carbon dioxide, heavy hydrocarbons and water. Then, using the reservoir natural pressure within a rectification column, methane is separated from nitrogen and helium. The resulting nitrogen-helium mixture is then compressed to ~20 MPa and cooled using liquid nitrogen to separate nitrogen from helium. This process yields technical-grade helium with a purity of 97–99%, which is subsequently refined to 99.99% purity (Nuttall *et al.*, 2012).

Helium production based on low-temperature liquefaction is the most commonly used method of helium recovery.

In Poland, helium production is handled by the ORLEN S.A. – PGNiG Branch at two gas denitrification plants in the Wielkopolska Petroleum Province: Odolanów (since 1976) and Grodzisk Wielkopolski (since 2009). These installations use a helium production method based on the low-temperature liquefaction process.

In this method moisture (water), carbon dioxide and heavy hydrocarbons are removed from helium-rich natural gas and then the resulting gas is cooled. Following the initial treatment the stream of gas is directed into distillation columns where it is separated into liquid methane (96%), liquid nitrogen and gaseous helium concentrate by exploiting their different boiling temperatures.

Helium concentrate (gaseous) is then treated again to remove inert components, namely hydrogen (via combustion) moisture (in separators and adsorbers), nitrogen and oxygen residues (by separation and low-temperature adsorption), and neon (by adsorption on activated carbon). Then, helium is recovered (through low-temperature condensation), via

a circulating compression-expansion cycle with concurrent heat exchange in exchangers (PGNiG, 2024).

However, since 2013, in addition to the methods described above, the ORLEN S.A. – PGNiG Odolanów Branch has developed another method of helium recovery, with the use of polymer membranes.

This innovative project was initiated in 2013 at the Kościan-Brońsko gas field (the Kościan S field and the Brońsko field do not have evaluated helium resources). Although the average helium content in Kościan S field is 0.1329 and 0.1382% vol. for the Brońsko field, these two gas fields are the largest providers of nitrogen-rich natural gas in Poland. The total budget of the polymer membranes project amounted USD 13.500. That method involves streaming a gas mixture (feed gas) along the surface of a polymer’s membrane, where it is separated into a stream enriched in helium (permeate) and a depleted stream (residual) due to the different permeabilities of the gases. Streaming of the gas mixture is enabled by the difference in pressure on each side of the membrane (PGNiG, 2017). The helium-enriched gas on the membranes (from 0.13 to ~0.8% vol.) is of low pressure and then directed by the pipeline for further purification, where it undergoes denitrification, purification and helium condensation.

ACCUMULATION AND PROSPECTS OF HELIUM-BEARING GAS DEPOSITS

⁴He originates primarily due to the radioactive decay of uranium (U) and thorium (Th) in the mantle and crust of the Earth (Danabalan *et al.*, 2022).

The primary migration is by diffusion-driven escape of helium from fine-grained minerals. Secondary migration of helium takes place along faults and fractures, facilitated by various carrier gases such as methane (CH₄), nitrogen (N₂), and carbon dioxide (CO₂) or by movement of groundwater containing dissolved gases (Torgersen, 1989, 2010; Cheng *et al.*, 2018; Qin *et al.*, 2022).

It is presumed that most helium (⁴He) eventually escapes into the atmosphere due to its low density and inert nature, but under specific conditions a portion of it becomes trapped within rocks. Achievement of equilibrium of groundwater containing dissolved ⁴He and N₂ with CO₂ or gaseous CH₄ allows the release of insoluble ⁴He and N₂ from the groundwater into the accumulated gas (Barry *et al.*, 2016, 2017). Geological traps for helium can be categorized as structural or stratigraphic.

Over the past century, helium-rich gas fields have primarily been discovered during oil and gas exploration, with helium detected through advanced gas analysis. However, many potential helium pay zones may remain unreported, as the standard gas chromatography equipment used for sampling is rarely helium-oriented. In response to the increasing global demand for helium, many countries have intensified efforts to develop advanced methods for exploring and evaluating helium within natural gas fields (Rolecki, 2021; Bereznicki, 2022; Danabalan *et al.*, 2022; Cheng *et al.*, 2023; Xiong *et al.*, 2024; Kosarzycki, 2024) or for trying to recover helium from geothermal brines (http://en.sasac.gov.cn/2024/10/28/c_18070.htm).

To assess helium prospectivity, it is necessary to determine the source of helium and also the processes driving its release from the source rock (primary migration), and to identify possible carriers that transport helium and the routes it follows to reach the reservoir rock (secondary migration,

Halford *et al.*, 2022). It is also important to understand the processes that cause helium to separate from its carrier and to accumulate within a reservoir trap as a free gas (Cheng *et al.*, 2023). The assessment of helium prospectivity requires also evaluating conditions for the sealing layer to retain helium effectively in a trap.

The analysis of helium-rich gas fields in Poland identified igneous rocks enriched in uranium and thorium as a source rock. Distribution of these source rocks has been correlated with the petroleum provinces defined by Karnkowski (1997), to delineate five prospective areas for the exploration of helium-bearing gas: Wielkopolska, Pomorze, Lublin, Gdańsk and Upper Silesia (Fig. 2).

A minimum average helium content in natural gas of 0,2% vol. entitles the user of a natural gas field to evaluate the helium resources. So far, such helium resources have been identified in 21 natural gas fields. The Lublin, Upper Silesia (except for the Goczałkowice-Dębina helium gas field), and Gdańsk areas have no record of evaluated helium resources, but they are considered highly prospective for helium exploration. A review of gas and gas-in-brine analyses performed in research boreholes drilled by the Geological Institute, and in conventional and unconventional oil and gas wells, will help constrain the presence of helium in deep aquifers in these areas, as is the case in the Lublin area.

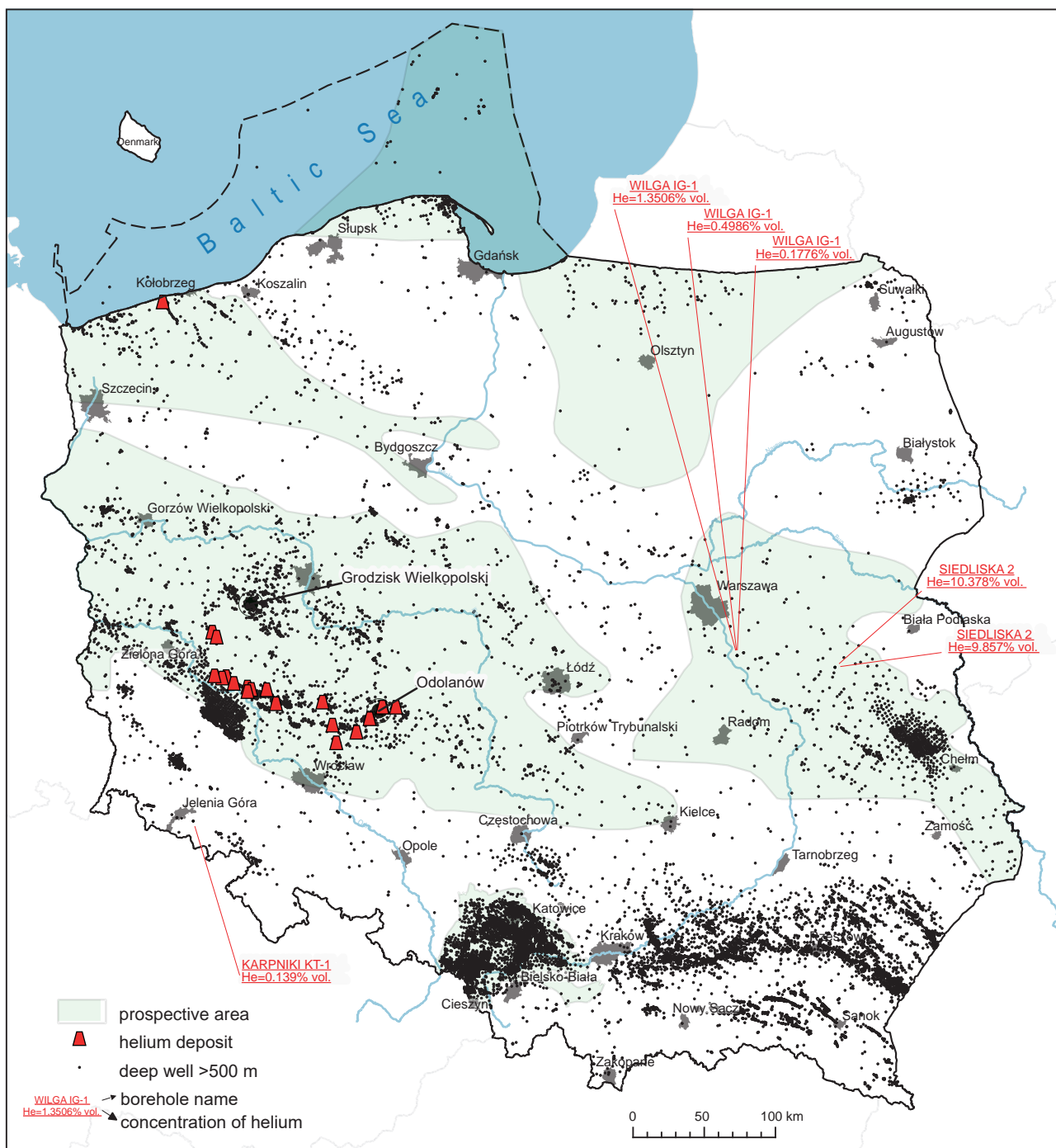


Fig. 2. Prospective areas, helium deposits, 15,105 deep wells (>500 m) (acc. to CBDG, 2024) and selected boreholes with helium concentrations

The Lublin area (eastern Poland), covering 33,026.23 km², is situated on the East European craton. Potential reservoirs of helium-rich natural gas in this area are associated with Middle Cambrian, Devonian and Carboniferous strata, which occur at depths ranging from 1,000 to 3,000 metres (Karnkowski, 1997; Stolarczyk *et al.*, 1997). In the Lublin area, increased concentrations of helium have been documented in Wilga IG 1 and Siedliska 2 boreholes within the Paleozoic aquifers (Table 4).

Most of the exploration work in the Lublin area was concentrated in the southeastern part of the area; 576 boreholes were drilled there to a depth of 1,000 metres or below, nearly 200 of which located within the hard coal deposits of the Lublin Coal Basin. Seismic survey, predominantly 2D, was concentrated in the southern part of the area, while the seismic coverage of the northern part is scarce and uneven. Four natural gas fields were discovered in the Lublin Trough: Mełgiew A and Mełgiew B (Devonian – Frasnian organo-detrital limestones), Ciecierzyn (Devonian – Frasnian calcareous dolomites), Wilga (Carboniferous – the Dęblin and Lublin formations). The average helium content in these gas fields ranges from 0.102 to 0.158% vol., while in two oil fields together with associated natural gas in the form of a gas cap – Glinnik (Devonian, in Famennian sandstones) and Stężycza (Carboniferous) – the average helium content ranges from 0.033 to 0.118% vol.

The Upper Silesian area, with an area of 5,627.98 km², is located in southern Poland.

The prospective reservoirs of helium-rich natural gas are the Carboniferous sandstone formations of the Cracow Sandstone Series, and Miocene sandstones occurring down to 4,000 m.

High helium concentrations were detected in gas samples from Upper Carboniferous sandstones in Upper Silesia in 1962, when analysing the absolute age of gas using the helium-to-argon ratio. These findings were recorded in the Rudółtowice Geo-1 and Dębina-3a boreholes located near the “Silesia” hard coal mine. Helium concentration

ranged from 0.33 to 0.41% vol. High helium concentrations were also found in other boreholes (Table 5).

Exploration carried out in Upper Silesia resulted in the discovery of the Goczałkowice-Dębina helium-bearing gas field.

The area of Upper Silesia is characterized by very good documentation of hard coal deposits and of coal bed methane. There are 2,816 boreholes reaching depths <500 metres. Seismic surveys are concentrated in the southern part of the area.

Two natural gas fields were discovered in the area: Kowale (Neogene – Miocene sandstones) and Dębowiec Śląski (Neogene–Miocene sandstones). The average helium content in these gas fields ranges up to 0.055% vol.

The Gdańsk area, with an area of 38,516.85 km², is located in the northern and northeastern part of Poland. Prospective reservoirs in this area are found in Middle Cambrian strata at the depth interval of 1,000–3,000 m.

This is the least explored prospective area. Only 230 boreholes reaching depths <1000 m have been drilled here. The coverage of 2D seismic is poor. 3D seismic images are concentrated in the northern and western parts of the area, i.e.: in the Łeba High area and in the offshore part, in the Baltic Sea. There is no seismic coverage of the southeastern part of the Gdańsk area.

There are three offshore natural gas fields with helium concentrations of 0.027–0.21% vol., namely: B 4 (Cambrian – quartz sandstones), B 6 (Cambrian – sandstones), B 21 (Cambrian – quartz sandstones). Within six onshore oil fields: Białogóra E (Cambrian – sandstones), Dębki (Cambrian – sandstones), Żarnowiec W (Cambrian – sandstones), Żarnowiec (Cambrian – sandstones), B 3 (Cambrian – sandstones) and B 8 (Cambrian – sandstones) – the average helium content of the associated gas ranges up to 0.187% vol. The latest studies on the B 101 structure showed an increased helium content in the degassed formation water (0.343% vol.).

Current understanding of helium appearance and its potential accumulations is based primarily on results of hydrocarbon exploration, as dedicated exploration for helium alone has never been conducted. Such dedicated helium exploration

Table 4. Helium concentrations from degassed brine in the Wilga IG 1 and Siedliska 2 boreholes (Sokołowski *et al.*, 2019)

Name of the borehole	Sampled interval [m]	Stratigraphy	Helium content [% vol.]
Wilga IG 1	2972–2985	Carboniferous	0.4986
	3113–3122	Upper Devonian	0.1776
	2263.5–2292	Permian	1.3506
Siedliska 2	2228–2281	Cambrian	10.378 (gas from degassed brine)
	2935–2913	Cambrian	9.857 (gas from degassed brine)

Table 5. Helium concentration in the boreholes from the Upper Silesian prospective area

Name of the borehole	Sampling depth [m]	Stratigraphy	Helium content [% vol.]
J-2/86	635 m – coal seam 510/1	Carboniferous – Saddle beds	0.46
Mk-2/90	857 m – coal seam 406/1	Carboniferous – Załęże beds	0.74
Mk-3	862 m – coal seam 406/2	Carboniferous – Załęże beds	0.35
P-2/76	574 m – coal seam 356/1	Carboniferous – Załęże beds	0.20
Z-4	611 – coal seam 404/4	Carboniferous – Załęże beds	0.21
Silesia S-1	140–156 m	Upper Carboniferous	0.30

should begin with compiling a comprehensive database of helium appearances in boreholes. This database should contain data on helium concentrations in natural gas fields and in aquifers. Prospective areas for helium exploration should be selected based on the analysis and interpretation of data from over 15,000 boreholes <500 m of depth (Fig. 2).

CONCLUSIONS

The unique physical and chemical properties of helium that determine its use in modern industries and scientific research, combined with the location of its deposits and resources around the world, caused the European Commission to reclassify helium as a critical raw material in 2023.

Poland is the only European Union country with evaluated resources of helium and is the only producer of helium in Europe.

The use of helium recovery membranes by ORLEN S.A. – PGNiG Odolanów Branch opens the way to the exploration of helium-bearing gas deposits in locations other than the Wielkopolska petroleum province.

Helium resources in Poland should be evaluated in all natural gas fields and oil fields with gas caps where the minimum average helium content is 0.2% vol. It should also be evaluated in all natural gas fields and oil fields with a gas cap, wherever ORLEN S.A. – PGNiG Odolanów Branch produces helium, even if the average helium content is <0.2% vol. This will enable estimation of helium resource and production values in Poland.

Poland, being the only European Union country with the appropriate technical capabilities, identified resource potential and prospective helium deposits, is well-positioned to initiate a dedicated program of exploration and potential production of helium.

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