Prospects of lithium extraction from geothermal brines and evaporite deposits in Poland

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A b s t r a c t. Due to the growing demand for lithium mainly related to the increase in the production of lithium-ion batteries used in electric or hybrid vehicles and in portable electronic equipment, and to a lesser extent also in other strategic fields (military, nuclear technologies), new lithium deposits are being searched for in many countries, as well as possibilities of extracting this metal from brines or evaporites. As a result, its global resources have doubled in the last six years, and, in 2020, lithium was included on the list of critical raw materials to the European Union economy. No lithium deposits have been identified in Poland yet, and all domestic demand is imported. The article provide an overview of lithium deposits and the prospects for lithium extraction from various types of minerals and brines in Poland, focusing on the possibility of recovery of lithium from marine evaporite deposits and geothermal brines. Among the evaporite deposits, the Upper Permian (Zechstein) evaporites deserve special attention, while among the brines, there are deep brine horizons in the Lower Permian Basin in western Poland, which is a continuation of the North German Basin, as well as the area of the Fore-Sudetic Homocline, and brines in the Zechstein carbonate formations, where numerous active or abandoned natural gas deposits are located. Analysis of available databases of deep boreholes, mine waters and geothermal facilities in Poland, shows that out of 816 physicochemical analyses of water in which the lithium content was determined, only in 13 cases its value exceeded 50 mg/l. The maximum content of 290 mg/l was recorded in brine from Permian from a depth of 3614 m in the Wyrzysk IG 1 borehole. It is recommended to explore the possibility of lithium recovery from evaporite deposits and geothermal brines in Poland. In addition to lithium, such research should cover other raw materials, including: boron, arsenic, magnesium, potassium, strontium, cesium, bromine, iodine and rubidium, because co-recovery is always more profitable than the recovery of a single element. Simultaneous energy production from thermal waters should be necessarily considered, because mineral recovery technologies are expensive and energy-consuming. This energy could also be sold, which would increase the profitability of the recovery installation.

Keywords: *lithium, CRM, lithium extraction, geothermal brines, evaporites, gas fields*

INTRODUCTION

Lithium is called the "white petroleum" of the modern energy sector and is crucial to Earth's energy future (Balaram *et al*., 2024). Due to its high reactivity, lithium does not occur in nature in a metallic form, but in chemical compounds with an ionic structure (e.g., salts, oxides, hydroxides). It has the highest heat capacity of all solid elements and is an excellent conductor of heat and electricity. Lithium is distributed throughout the Earth's crust, occurring in both crystalline and sedimentary rocks, particularly in clays. During weathering and sedimentation, lithium is easily absorbed by secondary aluminosilicate minerals, which increases its content in clay deposits (Kabata-Pendias, 1997). The average lithium content in the Earth's crust is 35 mg/kg and in clay deposits 60 mg/kg. In igneous rocks, alkaline rocks contain only 10 mg/kg and acidic rocks 30 mg/kg. The lithium content in hard coals may reach 354 mg/kg (Shao *et al*., 2022), while in coal ashes it may exceed 0.1% Li_2O (Valkovic, 1983), though in Poland, lithium has practically not been determined in coal ashes. The authors of this article found only a few results of lithium concentration determinations in coal ashes from the Upper Silesian Coal Basin (USCB), but these were low values, <15 mg/kg. The concentration of lithium in the USCB coals is also low, around a few mg/kg (Winnicki *et al*., 1965). Concentrated lithium occurs mainly in the rocks of the upper layers of the Earth as lithium silicate, and in salt lakes as lithium carbonate and lithium chloride. In groundwater, it occurs as a product of weathering and the leaching of minerals. The rapidly growing demand for lithium is primarily related to the increase in the production of lithium-ion batteries used in electric and hybrid vehicles and in portable electronic equipment, and to a lesser extent in other strategic areas (military, nuclear technologies). In 2020, lithium was included for the first time on the list of elements critical to the economy of the European Union. As many countries are searching for new lithium deposits, as well as analyzing the possibilities of obtaining this metal from recycling, its global resources have doubled over the last six years. Szlugaj and Radwanek-Bąk (2022)

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reported that there are no lithium deposits in Poland, and the entire domestic demand is covered by imports. In the past, the occurrence of lithium was studied in pegmatites of the northern parts of the Karkonosze Mountains (Kozłowski, 2002), brines pumped during the drainage of hard coal and copper ore mines (Fijałkowska *et al*., 2008), waters accompanying hydrocarbon deposits (Uliasz-Misiak, 2016), in thermal and medicinal waters (Tomaszewska, 2018), in Permian brines accompanying rock salt deposits (Tomassi-Morawiec *et al*., 2019), and in groundwater pumped from selected facilities in Poland (Razowska-Jaworek *et al*., 2021, 2022). Preliminary investigations into obtaining lithium from brines in Poland was carried out as part of the EU BrineRIS project completed in December 2024 (Kowalewska, Worsa-Kozak, 2024; BrineRIS, 2025).

TYPES OF DEPOSITS AND MINERALS THAT CAN POTENTIALLY BE USED FOR LITHIUM EXTRACTION IN POLAND

Although lithium is commonly found in nature, there are only a few sources of lithium of significant economic importance. These include pegmatites, continental evaporites (salt lakes and marine evaporites), clay minerals containing lithium (montmorillonite, illite and chlorite), geothermal brines, as well as brines associated with oil and gas deposits. Important carriers of lithium in both granitic rocks and sandstones, especially those formed as a result of mechanical disintegration of granites, are white micas and biotite (Sanjuan *et al*., 2022). Lithium is a mobile element, and its main source in groundwater is from the weathering and leaching of minerals from igneous and sedimentary rocks (Macioszczyk, Dobrzyński, 2002). There are large regional variations in lithium concentration in groundwater. Lithium content in natural, fresh groundwater in Poland ranges from 0.002 to 0.04 mg/L, and the highest concentration is associated with the zone of terrestrial salinities. The highest recorded content of this metal (up to hundreds of milligrams per litre) is associated with highly concentrated calcium-chloride relict brines. A preferential environment for lithium migration, mainly in the form of the Li^+ cation and the $LiSO_4^-$ anion, occurs in acidic waters (Macioszczyk, Dobrzyński, 2002).

Pegmatite deposits with lithium mineralization

These deposits are most often associated with granitoid LCT (lithium-cesium-tantalum) pegmatites or strongly alkaline pegmatites. They usually have a typical zonal structure and contain lithium aluminosilicates: spodumene, petalite, lithium micas (e.g., lepidolite, tinwaldite, effesite) and amblygonite (lithium phosphate). They occur near granitoid intrusions, mainly in Precambrian rocks, on all continents. Coarse-grained mica granites with lepidolite are of minor importance (Balaram *et al*., 2024).

Lithium extraction from pegmatites involves conventional mining techniques, followed by crushing, milling and enrichment processes to concentrate lithium minerals. Chemical post-treatment is used to extract lithium compounds such as lithium carbonate and lithium hydroxide (Margarido *et al*., 2014). Extraction of lithium from pegmatites may have negative impacts on the environment, including disturbance of terrestrial habitats and aquatic environments, although efforts are currently being made to improve the sustainability of lithium extraction and processing. Among European countries, lepidolite pegmatites are known and have long been exploited in Portugal (Barroso-Alvao, Guarda-Goncalo), Spain (Fregenda-Almerenda), the Czech Republic (Cinovec) and France (Sanjuan *et al*., 2022). Currently, new exploration works are underway in Europe to assess lithium resources, as well as co-occurring tantalum, in this type of deposit (Krzak *et al*., 2021). In recent years, thanks to intense exploration, new pegmatite deposits have been discovered in Austria (Wolfsberg), Finland and Germany.

Gajda (1959), during reconnaissance work in the Karkonosze Mountains, negatively assessed the potential of lithium deposits in this region, with the exception of the Bystroń-Szklarka outlet zone, where pegmatite masses were considered to be prospective in terms of lithium content. In the Góry Sowie Gneiss Massif area, in two quarries in Piława Górna and Lutomia, there are pegmatite veins containing lithium minerals such as spodumene and lepidolite. These pegmatites are associated with volcanic and intrusive activity, which favors the formation of large crystals and the concentration of rare elements, including lithium. The pegmatites occurring there are referred to as mixed LCT and NYF veins (Pieczka *et al*., 2003, 2010). This area may have potential for lithium deposits, so it would be worth performing detailed geochemical studies in these quarries.

Clay minerals containing lithium

These minerals are associated with volcanic zones and usually form lenticular accumulations during sedimentation in arid climates. The main mineral is hectorite (a type of magnesium-lithium smectite) containing lithium, which is formed during hydrothermal alteration of volcanic ash or by direct precipitation from salt solutions. Bentonite and hectorite are mainly used in the gas and oil industry (as drilling fluids), but recently also as a source of lithium (Balaram *et al*., 2024). A concentration of hectorite was discovered in the Bigadian borate deposit in Turkey (Szlugaj, Radwanek-Bąk, 2022). Jadarite (lithium zeolite) occurs in the Jadar Basin in Serbia. Jadarite occurs there both in a massive form, forming a layer over 7 m thick, and in the form of nodules in a fine-grained carbonate matrix. The resources of this deposit are estimated at over 125 million tonnes of the mineral with an average Li_2O content of 1.8% (Brown *et al*., 2016). The possibility of the lithium deposit occurrence in clay-rich rocks in Poland has not been investigated yet.

Lithium in continental brine deposits (salars)

Salars occur in dry, often high-mountain climates, where there is a predominance of evaporation over precipitation. They are associated with igneous rocks, which can be the main source of lithium, and in zones of geothermal activity. Salt lakes usually occupy large areas. They occur mainly in South America (Chile, Argentina, Bolivia), North America and China (https://pubs.usgs.gov/publication/mcs2024). Lithium occurs in carbonate or chloride form, co-occurring with many other elements, such as: Na, Br, K and B. These deposits are classified as evaporites due to the major role of this process in forming lithium concentration in the deposit. The profitability of exploiting salar deposits of lithium-containing brine results from the fact that their deposits are large, favour open-pit mining, and lithium extraction is uncomplicated. There are no prospects for deposits of this type in Poland.

Lithium in marine evaporites

Lithium deposits of this type in Poland have not been systematically examined so far, and lithium content has only been determined as a part of mineralogical-petrographic and geochemical studies of Permian (Zechstein) and Miocene evaporites. In the Zechstein evaporites, the presence of lithium has been documented, for instance, in the polyhalite-bearing succession within the first Zechstein evaporate cycle (PZ1) in the Puck Bay area, where lithium content ranged from 15.1 to 59.6 mg/kg (Czapowski *et al*., 2022). In the Kłodawa Salt Structure, the lithium content was determined at 5.6 mg/kg based on a few analyses of potash-bearing series of the PZ2 and PZ3 evaporite cycles (Mazurek *et al*., 2016). Increased lithium content (193.1 ppm) was also recorded in the Mogilno Salt Dome in clayey salts of the PZ3 cycle (Brown Zuber, Na_3t) (Wachowiak, 2016), while in brines flowing out spontaneously during drilling of the test borehole, the lithium content was determined at 158–268 mg/L, with the outflow appearing during drilling through a zone of the PZ3 cycle rocks, with Na_3t clayey salts (Wachowiak, Kasprzak, 2014). Clayey salts occurring in the Zechstein Basin of Germany, equivalent to the Na_3t in Poland, contain lithium concentration of up to 161 mg/g (Onneken *et al*., 2017, 2018). No comprehensive studies of lithium content in the Miocene evaporites have been conducted in Poland so far. Considering the significant share of clayey salts in the Miocene salt succession of the Carpathian Foreland, an increased lithium content, analogous to that of the Zechstein clayey salts, should be expected.

Lithium in geothermal brines

Elevated lithium content in geothermal brines results from a complex history including periods of evaporation, mixing of waters of different origins, and dissolution and precipitation of minerals such as halite and hectorite. The original concentrations are assumed to be related to tectonic activity, volcanism, and high water temperatures (Garret, 2004). Geothermal brines occur in most geothermal basins in the world. In Europe they have been recognized in Iceland (Reykjavík area), Italy (Cesano and Campi Flegrei), France (Alsace, Upper Rhine area), and in Germany in the North German Basin and South German Molasse Basin areas. They contain a maximum of 480 mg/L of lithium (Sanjuan *et al*., 2022). Currently, thermal waters from the Salton Sea in California (USA) are used, which contain lithium at concentration of 100–200 mg/L (Brown *et al*., 2016), and where 11 power plants provide over 370 Mw of energy. Geothermal brines are formed by hot, concentrated salt solutions (hydrothermal) circulating in the rocks of the Earth's crust in areas of exceptionally high heat flow and becoming enriched in elements such as lithium, boron and potassium. Mixing of relict seawaters and leaching of minerals are the most important factors controlling lithium concentrations in such thermal reservoirs (Brown *et al*., 2016). However, such deposits are limited to continental basins where volcanic rocks occur. In Europe, only six areas with deep brines containing high Li concentration, ranging from 125 to 480 mg/L, have been identified so far in Italy, France, Great Britain and Germany (Gourcerol *et al*., 2024). Since the deposits in Germany occur in the North German Basin, e.g. in the Groß Schönebeck area (Table 2 and Fig. 1; Alms *et al*., 2025), which continues into Poland, there is a high probability that brines with lithium content >200 mg/l occur in the western part of the Lower Permian Basin in Poland, in the vicinity of Poznań, Gorzów Wielkopolski, Zielona Góra, Krosno Odrzańskie, Słubice and north-east of Szczecin. Brines from the German Lower Permian formations, located near the border with Poland, apart from high lithium content, are characterized by high temperatures, exceeding 100°C (Regenspurg *et al*., 2016). Figure 1 shows the approximate locations of prospective areas for recovery of lithium and other elements from geothermal brines. The extent of Permo-Carboniferous volcanic rocks was determined based on Maliszewska *et al*. (2016). Combining geothermal energy with the recovery of elements, including lithium, could provide clean energy and valuable minerals. Lithium recovery from such brines may prove to be one of the most promising sources of this metal in Poland.

Brines accompanying hydrocarbon deposits

Deep oil and gas deposits account for 3% of the world's known lithium resources. Due to the accumulation of lithium as a component of many organisms, elevated lithium levels are often observed in brines accompanying hydrocarbon deposits, but lithium can also be formed in these brines as a result of reactions with salt solutions containing phyllosilicates (Mertineit, Schramm, 2019). Brine produced during oil and gas abstraction is usually considered waste and is injected back into the well to avoid the risk of contamination. In addition to lithium, these brines contain elevated levels of magnesium, bromine, and potassium. Lithium content in brines extracted from oil and gas fields is in the range of 80–500 ppm (Lee *et al*., 2022), e.g. lithium content in brine at a depth of 1800–4800 m below the surface of an oil field in Arkansas (USA) is 500 ppm (Garret, 2004). Bromine has been recovered on a large scale from this brine since 1969, and efforts were made in 2010 to develop the technology and build a pilot plant for lithium recovery (Brown *et al*., 2016). The company completed a pre-feasibility study in 2023, demonstrating good project profitability and the potential to produce up to 35,000 tonnes per year of lithium hydroxide over a 20-year operational period. They are currently in the process of developing a final feasibility study (https://www.standardlithium.com/).

In the area of the Fore-Sudetic Homocline, prospective waters for lithium extraction may be those originating from the Zechstein carbonate formations, which host numerous exploited or abandoned deposits of natural gas (including Żakowo, Tarchały, Uników, Antonin, Rawicz, Kąkolewo, Janowo, Bogdaj-Uciechów) and crude oil (Czerwieńsk, Pomorsko, Gomunice). In the oil and gas fields, there are operating wells, as well as those in which exploitation has been abandoned due to the unprofitability of extraction caused by the depletion of deposits or for other reasons, e.g. technical problems or a large inflow of brine. These wells can be used to access horizons of saline waters with a significant content of valuable elements, including lithium. Tests of formation water samples and the results of chemical analyses of formation water conducted during hydrocarbon exploitation constitute an additional source of information, helpful both in selecting the most prospective "horizons" and areas where waters with a significant content of individual components (including lithium) occur.

LITHIUM CONTENT IN GROUNDWATER IN POLAND

In order to assess the content of lithium in groundwater in Poland, a review of the results of physicochemical analyses of water in available databases of deep boreholes, mine waters and geothermal facilities was conducted (Table 1). Data on lithium content were found in 816 samples. In 75 analyses the lithium content exceeded 10 mg/L, in 13 analyses 50 mg/L, including 6 analyses with Li over 100 mg/L (Bojarski, 1996; Bojarski *et al.*, 1996 and http://spd.pgi.gov.pl/PSHv8/Psh.html; http://otworywiertnicze.pgi.gov.pl). The highest lithium concentration of 290 mg/L was recorded in the Wyrzysk IG 1 borehole in Permian brine at a depth of 3614 m (Table 2 and Fig. 1), with 268 mg/L in Zechstein brines of the Mogilno Salt Dome, 265 mg/L in Urzuty IG 1 borehole and 217 mg/L in Lelechów IG 1 borehole (Szpakiewicz, 1983). Concentration >100 mg/l was found in Permian brine in the Objezierze IG 1 borehole at a depth of 4160 m (Table 2 and Fig. 1) and in the PGNiG "Bogdaj-Uciechów" gas well (Razowska-Jaworek *et al.*, 2022).

The content of lithium in groundwater does not depend on the depth or temperature of these waters: it depends to some extent on the Total Dissolved Solids (TDS) and the content of sodium, potassium, and to a slightly lesser extent on the content of chlorides, bromine, boron and strontium (Table 3). As part of the task "Initial analysis of the possibilities of obtaining elements from groundwater", carried out under the State Raw

Table 1. Lithium concentration in waters from deep boreholes, medicinal waters and mine waters

	Li [mg/L]
N	816
Maximum	290
Minimum	0.002
Average	4.9

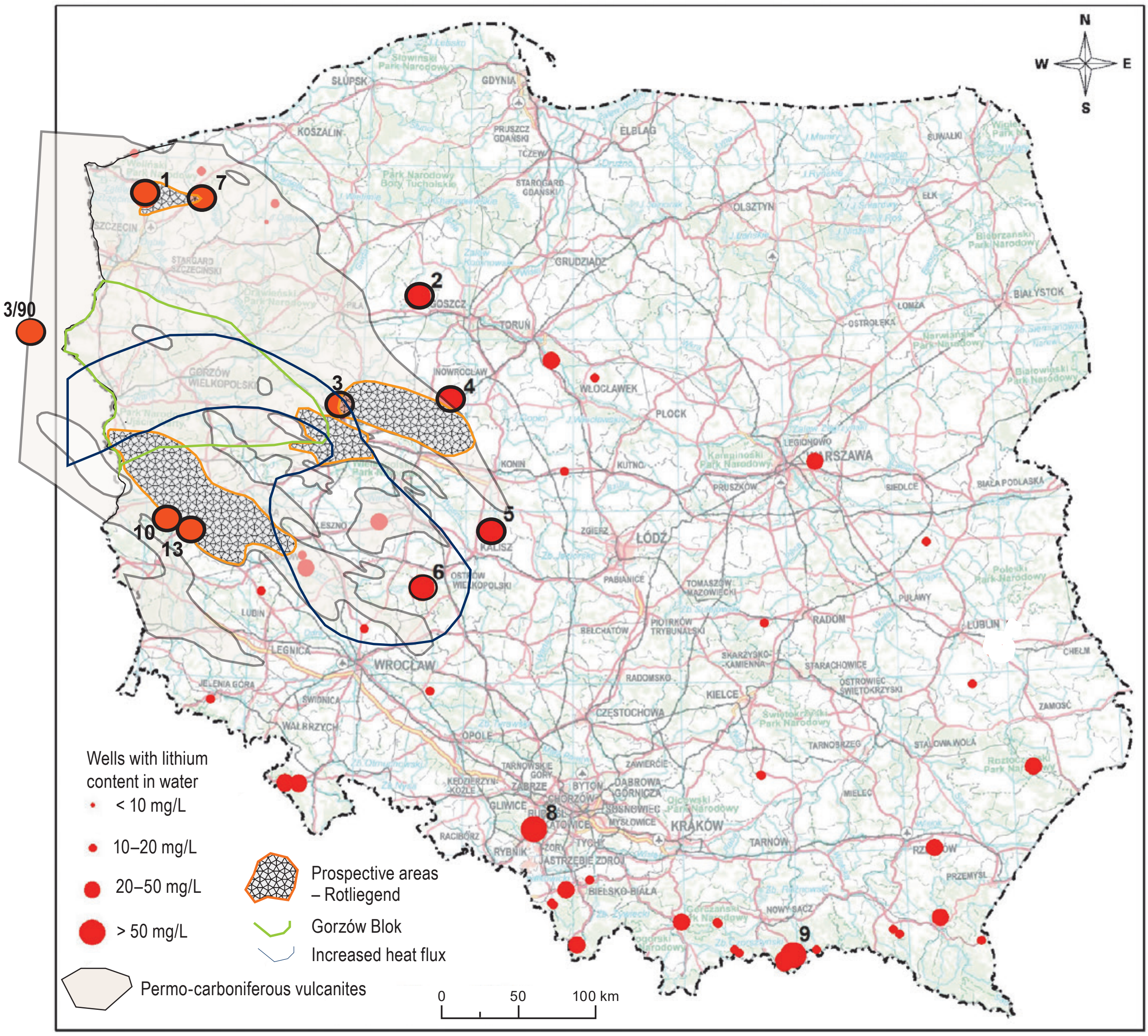

Fig. 1. Lithium content in groundwater and prospective areas of geothermal brines with lithium recovery potential in Poland; well numbers in Table 2 (after Razowska-Jaworek *et al.*, 2022, modified)

Materials Policy (Razowska-Jaworek *et al*., 2021), the possibilities of lithium recovery from water produced in geothermal facilities, mine waters and water pumped during natural gas exploitation in Poland were analysed. Seventy five water samples were taken from selected facilities and afterwards physicochemical analyses of these waters were performed. In the tested waters, lithium content ranged from 0.005 to 100.0 mg/L, with the average value 4.86 mg/L. The highest values were found in water from the "Bogdaj-Uciechów" natural gas field and in the gas fields in the Wielkopolska region (25–32 mg/l) and in concentrated brine from the mine water desalination plant in Dębieńsko (55 mg/l). Those studies also attempted to determine approximately lithium resources in groundwater. The highest resources were estimated for the "Dębieńsko" Desalination Plant (several tens of tonnes/year), the copper ore mines "Rudna" and "Polkowice-Sieroszowice" (several tonnes/year) and the "Olza" mine water collector (several tonnes/year).

Criteria proposed for determining lithium deposits in brines in Poland

The minimum lithium content in geothermal brines required for economically viable recovery can vary significantly, depending on several factors, including:

- extraction method and cost – technologies such as ion exchange and adsorption may be more cost-effective at lower concentrations, while methods such as solvent extraction may require higher lithium content to be cost-effective. Direct lithium extraction (DLE) technologies are particularly important in ensuring greater profitability for recovery from lower lithium concentration brines;
- market prices – the profitability of recovery depends to a large extent on the market price of lithium compounds. Higher market prices may justify recovery of lower lithium concentration brines;
- scale of the project – larger-scale production is more cost-effective, allowing profit even at lower lithium concentrations. Conversely, smaller plants may require higher lithium concentrations to make recovery economically viable;
- "co-recovery" of other elements – if other valuable minerals or elements are present in the brine (e.g., boron, magnesium, potassium, strontium, rubidium), combined recovery may increase the profitability of the project.

The generally accepted threshold for economically viable lithium recovery from geothermal brines is a minimum of 100 mg/l, but recovery from brines with lithium concentrations >200 mg/l is considered more cost-effective (Gallup, 1998; Neupane, Wendt, 2017). Below this range, the costs associated with extraction and processing may outweigh the benefits unless favorable conditions exist, such as high market prices or the presence of other valuable elements.

ANALYSIS OF THE PROSPECTS FOR LITHIUM RECOVERY IN POLAND

Lithium extraction from marine evaporite deposits

The most prospective areas for lithium extraction in Poland are the Permian (Zechstein) and Miocene evaporites. In examining these in more detail, firstly, focus should be on geological structures hosting operating mines (hence, with good knowledge on their geology) and areas of prognostic and prospective occurrence of rock salts and potassium-magnesium salts, as specified in the "Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r." (Balance of prospective mineral resources as of 2018 – in Polish), should be selected (Szamałek *et al*., 2020). The best documented geological structures built of Permian (Zechstein) evaporites are: the Kłodawa Salt Structure, where direct sampling of the most prospective sections of the Zechstein profile may be carried out in an underground mine; and the Mogilno and Góra Salt Domes, exploited using the leaching method, enabling hydrogeochemical sampling of brines (Fig. 2). The prospective area for pilot recognition of lithium content in Zechstein evaporites is also the Fore-Sudetic Homocline in the areas of expected occurrence of potassium-magnesium salt deposits. Within the Miocene evaporites, the best known geological structures are salt deposits near Wieliczka and Bochnia, where it is possible to directly sample the evaporite succession in underground mines.

The presence of lithium in evaporite rocks, and in brines circulating within them, indicates the validity of systematic sampling of the evaporite succession in order to determine the lithium content and its variability

Table 2. Brines with lithium concentration over 50 mg/L (after BrineRIS, 2024, modified and extended)

No. (Fig. 1)	Name	Description	TDS [g/L]	Li [mg/L]	Mg [mg/L]
1	Moracz IG 1	borehole	234.0	90	572
2	Wyrzysk IG 1	borehole	328.5	290	1920
3	Objezierze IG 1	borehole	247.1	102	1710
4	Mogilno M-32	salt dome	397.2	268	74070
5	Zakrzyn IG 1	borehole	367.1	74.5	3000
6	Bogdaj-Uciechów 11	gas well	287.0	100	1200
7	Piaski IG 2	borehole	312.9	85.7	10200
8	Dębieńsko	desalination plant	313.0	55	19200
9	Krynica Zuber IV	medicinal water	27.8	54	513
10	Urzuty IG 1	borehole	350.0	265	nd
13	Lelechów IG 1	borehole	348.8	217	nd
3/90	Groß Schönebeck 3	borehole	261.9	230	379

Table 3. Correlation coefficients of lithium content with other parameters and components in the studied waters

Parameter	Depth [m]	TDS [g/L]	Temperature [°C]	Cl	Ca	Mg	Na	K	Fe	Br	Ba	B	Sr
				[mg/L]									
Li	0.50	0.83	0.30	0.68	0.50	0.67	0.81	0.78	0.41	0.67	0.55	0.69	0.69

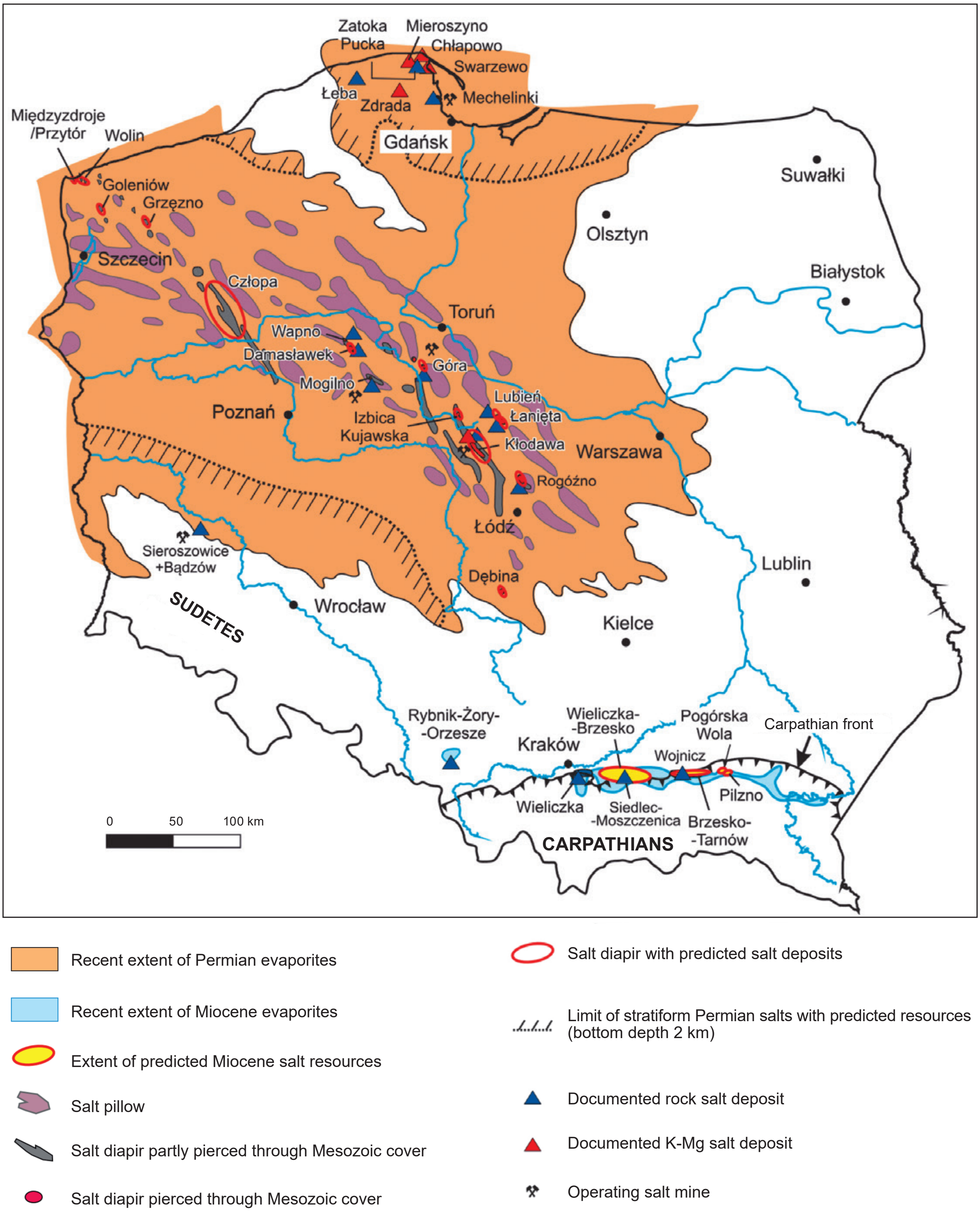

Fig. 2. Map showing the distribution of documented rock salt and potassium-magnesium salt deposits in the Zechstein and Miocene evaporites in Poland (according to Czapowski *et al.*, in: Szamałek *et al.*, 2020)

in the Zechstein and Miocene stratigraphic profile. Such analysis should be performed together with the analysis of the content of other critical elements: boron, magnesium and strontium, as well as rare earth elements and potassium, because lithium can accompany other elements occurring in an economic accumulation in the deposit.

Lithium recovery from geothermal brines

Taking into account both, the ecological aspects and the potential economic benefits of recovering raw materials from brines, searching for methods of recovering lithium from highly mineralized thermal waters seems justified.

Information obtained from published results of studies suggests several objects suitable for more detailed studies. These are, apart from the evaporite deposits described above, deep boreholes within the most prospective parts of the Permian Basin (Fig. 1), natural gas deposits, mine waters and geothermal facilities. An analysis of geological premises, hydrogeological parameters and interpretation of the collected results of physicochemical and isotopic analyses of waters would allow the selection of the best prospective areas for the location of a borehole to explore geothermal brines with the most favorable composition, taking into account the possibility of co-recovery of lithium and other elements toge-ther with the production of heat energy. As the lithium in brines originates mainly from the dissolution of igneous (volcanic) rocks, the most promising areas would be where volcanic rocks occur in the basement of brine aquifers such as the Lower Permian deposits in the western Poland (Fig. 1).

In order to recover lithium from brines, substantial research and development takes place on the use of various methodologies such as membrane technologies, precipitation, extraction with solvents, electrochemical systems and ion exchange. According to Tomaszewska (2018), higher lithium content can be obtained via water concentration processes, which, depending on the process used and operating parameters leads to lithium concentration that is about 3 or even 4 times higher than in the geothermal brine. However, high concentration of magnesium ions constitute a barrier to lithium recovery because both Mg^{2+} and Li^{+} are positively charged ions and their sizes are very similar (0.072 nm for magnesium and 0.076 nm for lithium, respectively); (Mends, Chu, 2023).

CONCLUSIONS

Our analysis indicates that there are prospective areas for lithium extraction in Poland, for which it would be necessary to carry out detailed studies on the possibility of lithium exploitation from marine evaporites or recovery from geothermal brines. In addition to lithium, these studies should include analyses of other elements, such as boron, arsenic, magnesium, potassium, strontium, caesium, bromine, iodine and rubidium. Whether the content of individual elements is prospective for recovery or somewhat lower, co-recovery will always be more profitable than the recovery of a single element.

Simultaneous energy production from thermal waters would also need consideration, because element recovery technologies are energy-consuming. This energy can also be sold, to increase the profitability of element recovery; particularly that lithium prices have decreased by ~80% in recent years compared to 2022, when they reached their highest values. The current decline in lithium prices can be attributed primarily to the slowdown in the growth of electric vehicle sales (e.g., in China, which is associated with the broader slowdown in the Chinese economy) (https://www.nasdaq.com/articles/lithium-market-forecast-top-trends-lithium-2025).

It is recommended to introduce a requirement to test and document lithium content when issuing concessions for the exploration and documentation of marine evaporite deposits, as well as lithium content in groundwater in the case of research or exploration boreholes for mineral waters and also other boreholes drilled at greater depths in Poland. It is also worth introducing a requirement to test and document lithium content when issuing concessions for the exploration and documentation of clay deposits.

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Graphite-quartzite schist, Nowa Ruda near Kłodzko, Sudetes.
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