SALT DEPOSITS IN POLAND (CENTRAL EUROPE): GEOLOGY, RESOURCES AND MANAGEMENT

Grzegorz CZAPOWSKI[1], Krzysztof BUKOWSKI[2],
Polish Geological Institute, Rakowiecka 4, 00-975 Warsaw, Poland;
e-mail: grzegorz.czapowski@pgi.gov.pl
University of Mining and Metallurgy, Al. Mickiewicza 30, 30-059 Cracow, Poland;
e-mail: buk@agh.edu.pl

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ABSTRACT

The rock salt occur in Poland (Central Europe) in two salt bearing formations of the Upper Permian (Zechstein) and the Neogene (Middle Miocene) age but the potash salts are located only in the Permian one. The total resources of rock salt are over 84 x 10^9 Mg with predominant Permian resources (4 thick complexes of rock salts, occupied the nearly 2/3 area of Poland, over 80 x 10^9 Mg in 15 documented salt deposits both of stratiform and diapir types). They are now exploited in 2 underground salt mines and 2 solution mines producing in 2007 ca. 3.1 x 10^6 Mg of rock salt mainly from the diapirs. The most perspective future management of these rock salt deposits are the safety underground cavern storages (for oil and gas, now 2 such ones exist) and depositories. The Neogene deposits (stratiform and stratiform-folded), exploited in the past millennium, occur in the limited area od southern Poland and are now only of historical-touristic value.

The potash salts, quite frequent within the Permian evaporate complexes, are documented in a single salt diapir in central Poland (mainly consisted of carnallite and kieserite, resources of over 72 x 10^6 Mg, minimal and accidental exploitation) and in sulphate horizons accompanied the rock salt seam in northern Poland (4 deposits of polyhalite with resources of ca. 0.67 x 10^9 Mg). Because of low market prices of potash products offered by the neighbouring countries e.g. Russia, Belarus, Ukraine, the future management of national potash salt resources seems to be non-economic.

INTRODUCTION

Rock salts occur in Poland in two evaporite formations: the early Neogene (Miocene) one, extended in the southern Poland (Carpathian Foredeep area) and the late Permian (Zechstein) one, occupied over a half of Poland area (fig. 1; Czapowski et al. 2008).

The Miocene salts have been exploited in prehistoric times but notations of salt mining are dated for XI century and the mines there were abandoned finally in 90thies of XX century. Resources of documented there 7 salt deposits (but now only 3 ones in statistic summariés) equal to 5.4 % of national rock salt resources.

The Permian (Zechstein) salts, both a rock salt and a potash, occur within four thick evaporate complexes at the depth from several hundreds meters (northern and SW Poland with 5 stratiform salt deposits) to several kilometers (Polish Lowland area in central Poland). In the Polish Lowland region are located numerous salt

domes (up to 7 km high), in some of which were documented during last 150 years the rock salt deposits. Their resources are estimated for 56 $x10^9$ Mg, equals 66.3 % of national salt reserves and salt produced from managed 3 structures in 2007 was almost the whole national salt production. Actually only the Zechstein rock salts are exploited (in three diapir salt deposits seasonally in a single stratiform one) but the 2 diapirs were managed for gas and oil products storages (fig. 1).

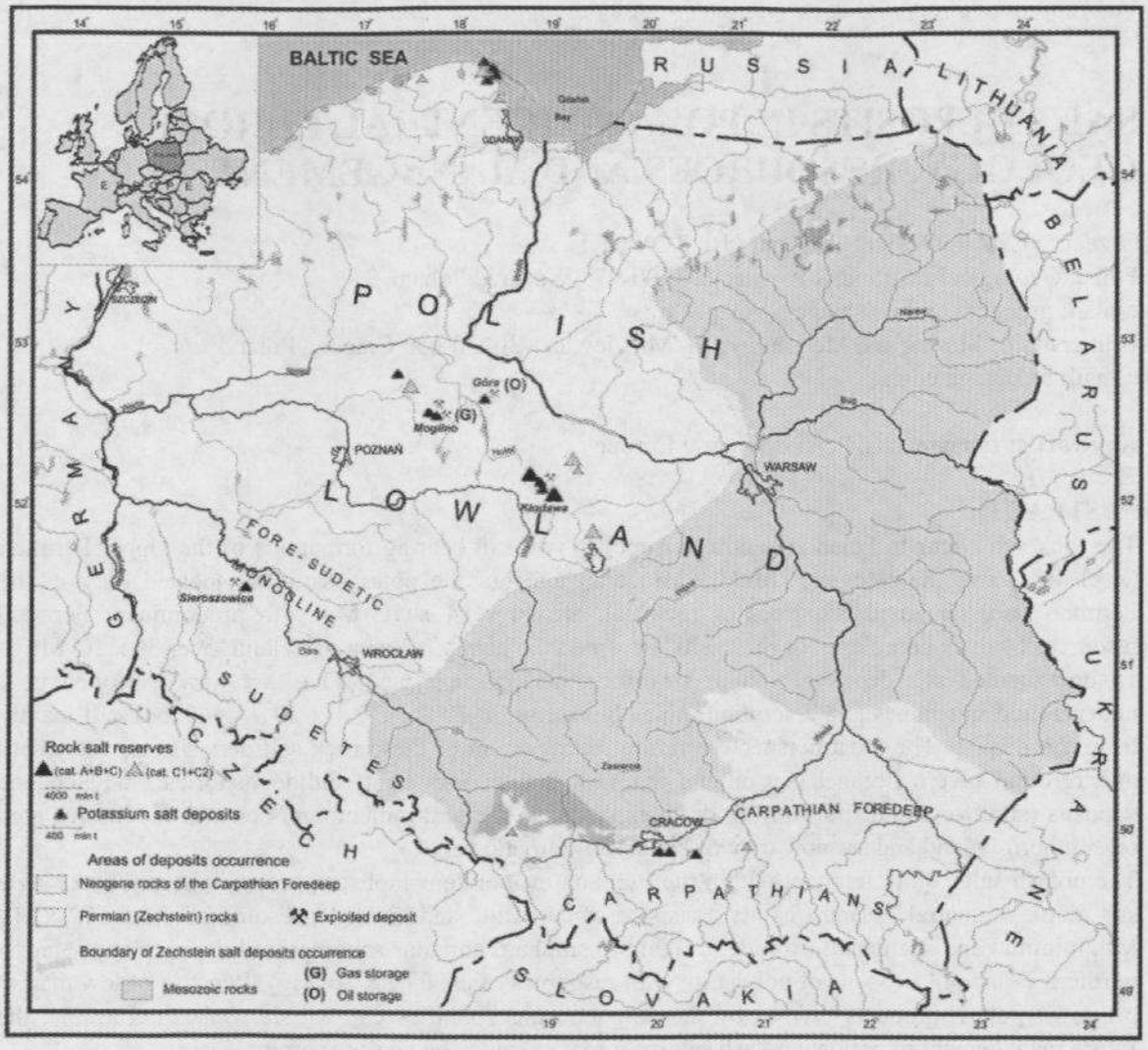
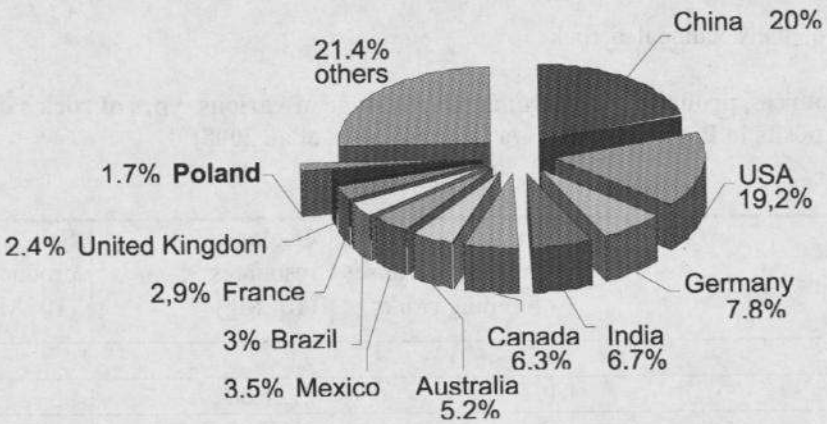


Fig. 1. Salt deposits in Poland.

Salt production in 2007 in Poland was 3.1 $x10^6$ Mg (tab. 1), including: 2.59 $x10^6$ Mg from the solution mines (Góra, Mogilno I, Mogilno II; data calculated from the brine volume) and 0.517 $x10^6$ Mg obtained from the underground mine Kłodawa (tab. 2; fig. 1). Also 0.06 $x10^6$ Mg of evaporated salt were produced in the saltworks. In 2006 the volume of rock salt produced in Poland (4.01 $x10^6$ Mg) equaled 1.7 % of the global salt production (fig. 2).

Fig. 2.The structure of the global production of salt in 2006 (after ww.saltinsitute.org)



In 2007 the balance geological resources of rock salt in Poland, estimated for 19 salt deposits were calculated for over 84.5 $x10^9$ Mg, but the outbalance ones – for 20.7 $x10^9$ Mg (tab. 1). Resources in 4 managed deposits were 12.6 $x10^9$ Mg, three deposits of Miocene salts (resources of 188 $x10^6$ Mg) were closed (and removed from the statistic list), but the remaining documented unmanaged 12 deposits (both of Miocene and Zechstein salts) contain ca. 71.7 $x10^9$ Mg of rock salt (tab. 1).

Table 1. Number, resources and management of rock salt deposits in Poland (after Gientka et al. 2008; resources calculated outside protection pillars)

Resources	Number of deposits	Geological resources (10^6 Mg)		Salt production (10^6 Mg)
		Balance (categories: A+B+C1+C2)	Outbalance	
Total resources	19	84511.72	20677.81	3.1
Resources of managed deposits				
Total	4	12588.33	7.77	3.1
Mined deposits	3	6890.83	7.77	3.1
Seasonally exploited deposits (cavern storage)	1	5697.51		-
Resources of unmanaged deposits				
Total	12	71735.51	20482.80	-
Deposits documented in details	5	27540.05	10017.78	-
Deposits preliminary recognized	7	44195.46	10465.02	-
Resources of abandoned deposits				
Total	3	187.88	187.25	-

The actual salt resources, a type and age of salt deposit, its state of management and annual production of the documented rock salt deposits in Poland are presented in table 2.

Table 2. Actual resources, production and management stage of various types of rock salt deposits in Poland (some data from Gientka et al. 2008)

Deposit name and age	Deposit management/onset of mining works	Geological resources (10^6 Mg)	Salt production (10^6 Mg)
I. Stratiform deposits			
ŁEBA (PZ)	P	2751.00	-
MECHELINKI (PZ)	R	2070.00	-
ZATOKA PUCKA (PZ)	R	16336.03	-
KAZIMIERZÓW/SIEROSZOWICE (PZ)	E/1991	2936.17	-
RYBNIK-ŻORY-ORZESZE (Ne)	P	2098.60	-
II. Stratiform-folded deposits			
SIEDLEC-MOSZCZENICA (Ne)	Z	187.88	-
WOJNICZ (Ne)	P	2083.00	-
III. Deposits in salt diapirs			
DAMASŁAWEK (PZ)	P	17690.43	-
GÓRA (PZ)	E/1965; M/1998	2336.71	1.010
MOGILNO I (PZ)	E/1978	3642.96	1.577
MOGILNO II (PZ)	M/1992	5697.50	-
LUBIEŃ (PZ)	R	4070.84	-
ŁANIĘTA (PZ)	R	2127.00	-
KŁODAWA PÓŁNOC (PZ)	P	6888.19	-
KŁODAWA CENTRUM (PZ)	E/1949	911.16	0.517
KŁODAWA POŁUDNIE (PZ)	P	4072.24	-
ROGÓŹNO (PZ)	P	8612.00	-

Explanations: P – deposit with preliminary recognized resources, R – deposit documented in details, E – deposit actually exploited, M – deposit managed as a cavern storage; Z – deposit with finished exploitation, Ne – Neogene deposit, PZ – Permian (Zechstein) deposit.

PERMIAN (ZECHSTEIN) ROCK SALTS

14 documented deposits of Permian salts (tab. 2; figs 1, 3), with the balance geological resources of over 78 $x10^9$ Mg, include: 4 stratiform deposits (resources of over 24 $x10^9$ Mg) and 10 deposits in 7 salt diapirs (resources over 53.9 $x10^9$ Mg). The active underground mines are located in one stratiform deposit (Kazimierzów/Sieroszowice) and in one diapir (Kłodawa) but 2 salt diapirs are exploited with leaching wells (Mogilno and Góra – tab.2; fig. 3), functioning also in a part as the gas and oil storages (Czapowski et al. 2008a, b; Karnkowski & Czapowski 2007; with references).

The stratiform deposits of Permian salts characterize with a quite simple geological structure. The largest such deposits were found in the northern Poland, westward from the Gdańsk Bay (fig. 3) and they are located within the single thick (up to 220 m) seam of rock salt (Na1). This seam inclined slightly to SE is at the

depth from 490.5 m to 1285.3 m and its varied thickness (0-225.5 m, average – 127.4 m) resulted from paleofacies variability (Czapowski et al. 2008b). Three large rock salt deposits (with total resources of over 21 $x10^9$ Mg, 25 % of total national salt reserves) were discovered and documented there in 1975-1980 (tab. 2): (a) Mechelinki deposit (area 6.4 km^2, resources ca. 2 $x10^9$ Mg), (b) Puck Bay deposit (area 101 km^2, resources ca. 16.3 $x10^9$ Mg) and (c) Łeba deposit (area 50 km^2, ca. 2.7 $x10^9$ Mg).

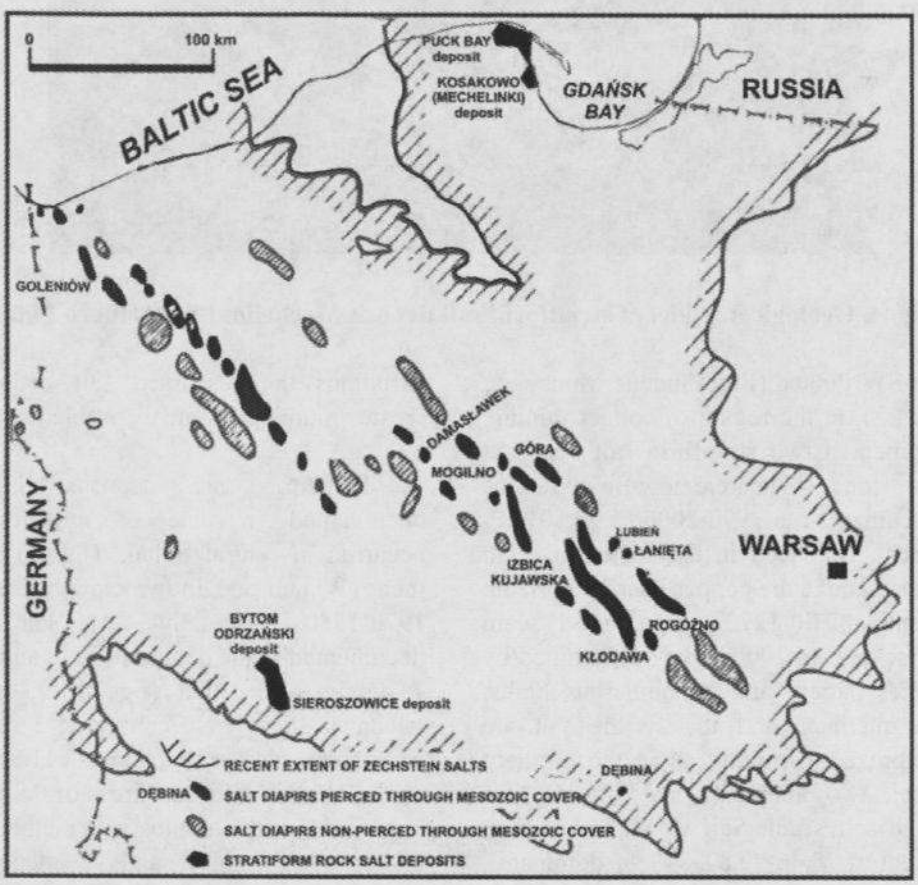


Fig. 3. Location of salt diapirs and stratiform rock salt deposits in Poland

All these deposits are build of almost homogenous rock salt seam (average NaCl content is ca. 96.7-97.8 %, insolubles up to 2.9 %), with rare, quite thin and not extended interbeds of K-Mg salts (mostly syn- and early diagenetic polyhalite) and sulphates, and only several fault zones cutting the salt seam. This seam is under- and overlain by two quite thick (several to 200 m) beds of anhydrite (A1d and A1g – fig. 4), being the perfect isolating horizons. Until now these deposits are not exploited but their structural features favor the option of possible deposits management as the underground storages and the radioactive waste depositories (Czapowski et al. 2008b; with references).

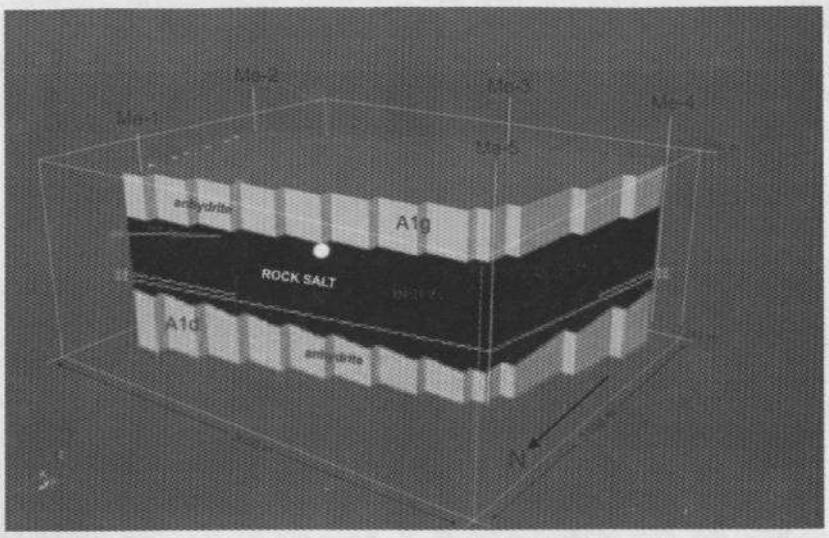


Fig. 4. Geological model of stratiform salt deposit Mechelinki in northern Poland

In SW Poland (Fore-Sudetic Monocline area; fig. 1, 3), in the region of copper mining, were documented two stratiform salt deposits. The first one, Kazimierzów/Sieroszowice deposit documented in 1990-2006 (2.9 x10^9 Mg of resources), is placed in the rock salt seam (Na1) located above the copper-bearing horizon, at the depth 827.0-1270.0 m. Varied seam thickness (several to 200 m) was determined by a paleofacies pattern and by numerous faults. Anhydrite interbeds and locally the salt are highly tectonized. Similarly as in the northern Poland area two anhydrite beds under- and overlain the salt seam. Salt characterizes with NaCl content of 75.46-99.82% (98% dominant), sulphates content is up to 6%. Salt is mechanically exploited in the galleries and chambers, accompanied the excavations system of the copper mines.

The second, unmanaged stratiform deposit Bytom Odrzański, placed north-westwards from the Sieroszowice deposit (fig. 3), contains 4 salt seams, lying one above other at the depths from 1039.5 m to over 1450 m, with thickness from several meters to 300 m. Sulphate, carbonate and claystone beds separate the salt bodies and NaCl content varies (88-98 %) accompanied with a high clay amount (5-8 %). The preliminary calculated whole salt resources are 48.76 x10^9 Mg (not included in statistics). Because of common tectonic deformations (faulting, fracturing) and salt thickness variations the discussed salt deposits could create more geological problems for future mining.

Hitherto salt deposits have been documented in nine of numerous diapirs occurred in central Poland (fig. 3) but two of them (Wapno and Inowrocław) were closed in 1970-1980. Actually 9 salt deposits, documented to the depths 1000 m and 1800 m in 7 diapirs, are listed (figs 1, 2; tab. 2), In Kłodawa diapir were contoured 3 salt deposits with total resources of over 11.8 x10^9 (the central deposit with resources of 0.9 x10^9 Mg is exploited with explosive method in the underground mine) and 2 deposits were distinguished in Mogilno diapir (total resources of over 3.8 x10^9 Mg, the Mogilno I deposit works as a solution mine but the Mogilno II deposit functioned from 1992 as the cavern gas storage).

The last managed Góra salt diapir (figs 1, 3; tab. 2), with resources of 2.3 x10^9 Mg, was exploited from 1968 with leaching wells and from 2002 several leached caverns were adapted for oil and oil products storages. Other 4 unmanaged salt deposits in 4 diapirs (Damasławek, Lubień, Łanięta and Rogóźno) offer the total balance resources of 32.5 x10^9 Mg.

Salt deposits in diapirs are characterized by a very complicated internal structure (e.g. Kłodawa diapir – fig. 5), resulted from varied

lithology and highly complicated tectonics. These features difficult a proper interpretation of diapir internal structure and consequently – calculation of salt resources and projecting of safety and economic mine excavations (both as an underground mine and as leaching caverns). Most of recognized salt diapirs in Poland have the younger Zechstein salt units (PZ3 and PZ4 cycles) in the upper part of salt trunk. Because they contain interbeds and a high admixture of potash salts, sulphates and clay matter so they are difficult bodies for realizing the proper storage caverns and mine chambers for salt excavation. The older Zechstein salt units (PZ1 nad PZ2 cycles) with lower potash and sulphate-clay admixture build commonly the lower part of diapir trunks so the most economic salt exploitation takes place at the lower levels.

The salt mirror in the dominant salt diapirs in Poland is located at the depth below 1500 m, the technical-economical limit assumed for location of storage caverns. In five ones (Goleniów, Damasławek, Lubień, Łanięta and Rogoźno – fig. 3) this mirror is placed at the depth less than 1 km, in 3 others (two in Wolin and one in Grzęzno in NW Poland) – at depth interval 1-1.5 km, so they could be managed in future as the cavern storages but after more detail geological recognition and reinterpretation of old data (Czapowski et al. 2008a; Karnkowski & Czapowski 2007).

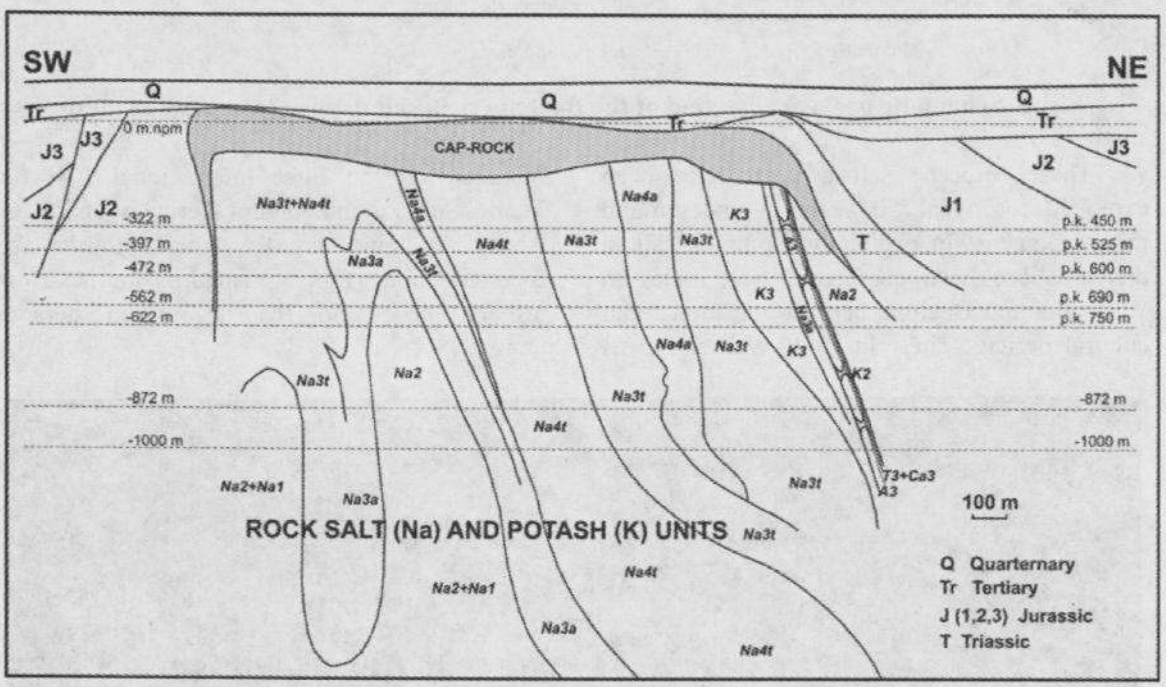


Fig. 5. Schematic geological section of Kłodawa salt diapir in central Poland

NEOGENE (MIOCENE) ROCK SALTS

The Neogene (Middle Miocene) salt deposits are located in the Carpathian Foredeep in southern part of Poland (fig. 1). Most of these deposits were folded (except the single stratiform Rybnik-Zory-Orzesze one, occurred in the tectonic depression of Upper Silesia region) in front of the Carpathian nappes and overthrusted from the south onto the autochthon series infilling the foredeep. Sediments of the salt-bearing formation which are intensively folded and imbricated occur at a depth from 50 m to 800 m (fig. 6). The salt layers are from several to several hundreds (tectonic duplication) meters thick and contain a considerable admixture of clay and anhydrite.

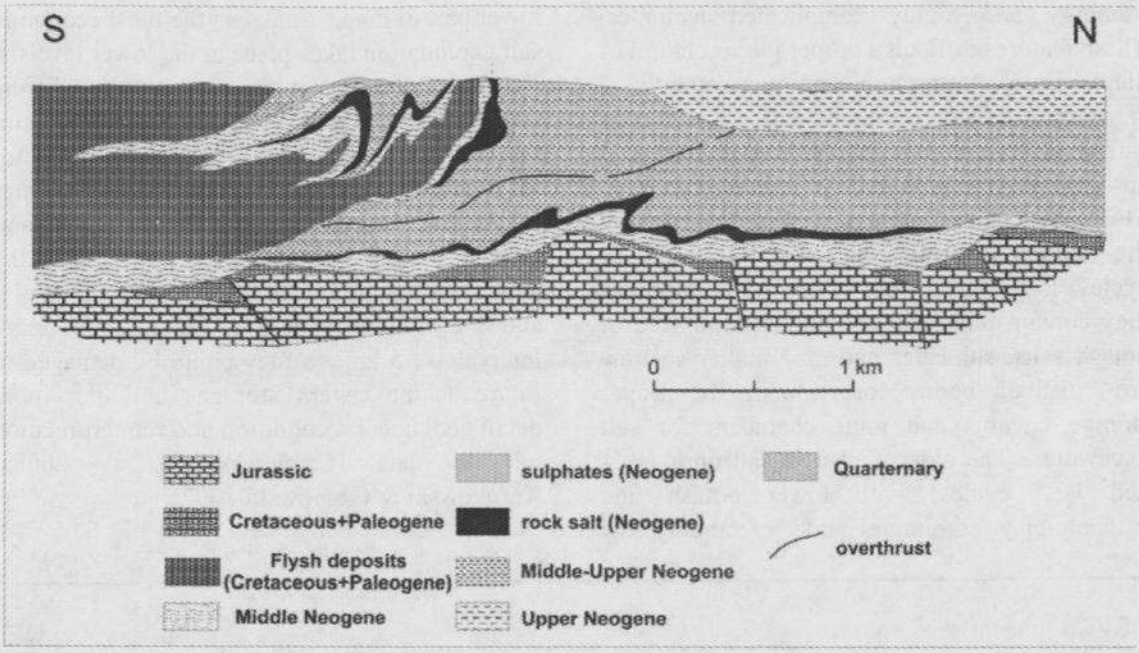


Fig. 6. Schematic geological section of the Bochnia rock salt deposit (southern Poland)

These Miocene salt deposits have been exploited for over 750 years in underground mines. Since 1996 exploitation of rock salt in this area has been completed. Salt mines in Wieliczka and Bochnia become the immaterial cultural heritage sites. In 1979 Wieliczka was included on the First International List the World Cultural and Natural Heritage UNESCO. Today the mines are the famous tourist and recreation sites (fig. 7), visited by tourists from around the world (ca. 1 million persons annually).

Fig. 7. Michałowice chamber. Wieliczka Salt Mine. Phot. Jerzy Przybyło

The balance geological resources of unmanaged 3 Miocene salt deposits (Rybnik-Zory-Orzesze, Siedlec and Wojnicz) are ca. 4.37 $x10^9$ Mg (tab. 2) being the equivalent to 5.17% of the whole Polish salt resources. Because of significantly greater resources and the higher quality of many Permian deposits as well as of complicated geological-mining conditions in the Miocene deposits these last ones probably will not be exploited both for salt and as the sites for underground storages/depositories in the near future.

POTASH SALTS

Potash salts in Poland are connected with the Permian (Zechstein) evaporate formation and occur as individual lithostratigraphic units (K2p and K3p; recognized in several salt diapirs e. g. Inowrocław, Góra, Mogilno, Kłodawa – fig. 3) and in SW Poland area as well as early diagenetic replacement of sulphate bodies in northern Poland (fig. 8).

The single potash deposit was documented in the Kłodawa diapir within the (K3p) salt unit (fig. 5). This potash seam is 15-30 m thick, composed of halite and carnallitic kieserite with average content of K_2O - 8.5% and of MgO – 8.1%. The balance potash resources are over 72 $x10^6$ Mg (tab. 3), but due to complicated geological structure of the deposit it was only sporadically exploited (1.4 $x10^3$ Mg in 2000).

Table 3. Actual resources and management status of potash salt deposits in Poland Bay (some data after Gientka et al. 2008)

Deposit name and age	Deposit management	Geological resources (10^6 Mg)	
		Total	669.111
KŁODAWA CENTRUM (PZ)	T	72.086	
CHŁAPOWO (PZ)	P	32.093	
MIEROSZYNO (PZ)	P	341.735	
SWARZEWO (PZ)	P	144.027	
ZDRADA (PZ)	P	79.170	

Explanations: P – deposit with preliminary recognized resources, T – deposit with documented resources seasonally exploited PZ – Permian (Zechstein) deposit.

The most important documented potash deposits of early diagenetic character (Peryt et al. 1998) are located in the northern Poland at the Gdansk Bay, accompanying the giant salt stratiform deposits. There were contoured in 1964-1971 four deposits of K-Mg salts (dominant polyhalite) with balance resources of 596 $x10^6$ Mg (tab. 3), being 89 % of the national potash resources.

Syn- and early diagenetic polyhalite was dispersed within: (a) the anhydrite interbeds in the rock salt (Na1) seam, (b) as dispersed aggregates in the rock salt seam and (c) in the upper part of anhydrite unit (A1d), underlying the salt seam. The first two forms of polyhalite dominate in the Chłapowo deposit and the last one composes the resources of Swarzewo and Zdrada deposits (Czapowski et al. 2008b).

The parameters of the mentioned potash deposits are listed in table 4. The depth of potash salt seams varies from 737.8 m to 858 m, their thickness achieves 73 m (average – 6-26 m) and K_20 content – up to 15.97 % (average – 7.74-13.78 %). Because of quite irregular distribution of polyhalite concentrations the proper estimation of the resources is very difficult and until now these deposits have not been exploited.

Table 4. Main geological and geochemical parameters of potash salt deposits at the Gdańsk Bay (northern Poland)

Deposit name and area (km^2)	Depth of the potash salt seam (depth interval) (m)	Potash seam thickness (thickness interval/average) (m)	Content of main salt component (content interval/average) (%)
CHŁAPOWO (3.55)	752.3-787.9	5.6-6.5/6.03	-/13.78 (K_20)
MIEROSZYNO (7.39)	737.8-802.0	1.9-73.0/26.02	7.74-15.97/8.75 (K_20)
SWARZEWO (4.56)	799.4-823.0	15.0-36.3/13.5	7.19-8.48/7.74 (K_20)
ZDRADA (2.25)	824.1-858.0	1.9-37.0/18.5	3.5-12.2/8.42 (K_20)

All these potash deposits are belonged to the elevations of the Zechstein evaporate basin palaeomorphology, build of the sulphate shoals (fig. 8). The basin depressions were then a place of intense chlorides accumulation, finalizing with the giant Puck Bay rock salt deposit.

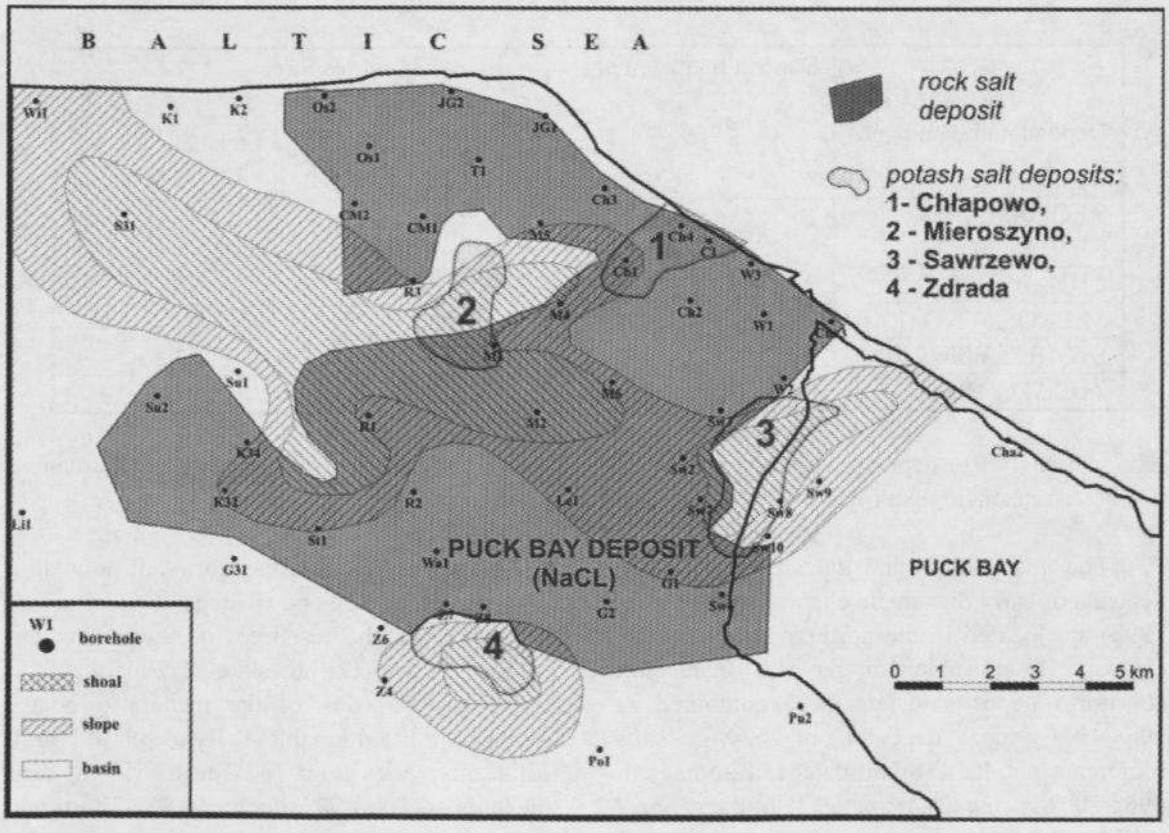


Fig. 8. Relation between the rock salt and the potash deposits in northern Poland on the background of Zechstein basin palaeomorphology

The potash salts occurred in the K2p and K3p salt units were found in many drills in the SW Poland (Fore-Sudetic Monocline) area. The K2p potash seam up to 30 thick was detected at the depth 917-1880 m and consists of dcm-1 m thick interbeds of halite+sylvine, halite+anhydrite+polyhalite with K_2O content 1-9 % (max. 25 %). The younger, K3p potash unit occurs at the depth 838-1068 m and it consists of two potash seams separated by a rock salt body: (a) lower one up to 6 cm thick (halite+anhydrite+polyhalite with K_2O content 1-4.5 %) and (b) upper one up to 12 m thick (sylvine+kieserite+polyhalite with K_2O content 1-16 %). These potash salts occurrences never have been documented as potash deposits.

CONCLUSIONS

From two salt-bearing evaporate formations in Poland only the Permian (Zechstein) one is now exploited for rock salt (not for potash salts). Its resources and geological recognition proves the future management both for salt production and for construction of safety oil-gas storages and waste depositories. The Neogene (Miocene) salt formation with several rock salt deposits (some have been exploited for centuries) are now not perspective for future mining because of complicated geological structure and varied salt parameters so the still existing mines were adapted as historical-recreation centers.

Four managed rock salt deposits (one of stratiform type: Sieroszowice and three in the salt diapirs: Kłodawa, Góra and Mogilno) are exploited for salt as underground mines (Sieroszowice, Kłodawa) and solution mines accompanied with gas-oil storage in leached caverns (Góra and Mogilno). The rock salt production from these deposits provides the national demand for salt in chemistry, agriculture and winter road protection.

Three large stratiform rock salt deposits, contoured in the northern Poland at the Gdańsk Bay (Puck Bay, Łeba and Mechelinki) could be quite easily managed both for salt production and cavern storages using the leaching method. Their simple geological structure, homogeneity of salt quality and rare potash-sulphate interbeds create the optimal conditions for such exploitation.

Several still unmanaged salt diapirs offer favorable conditions for construction of underground storages and depositories but because of complicate internal structure they require the detailed geological recognition.

The potash salt concentrations belong to the Permian formation and only 5 potash deposits have been hitherto documented. They accompanied the rock salt deposits and one is located in the Kłodawa diapir (sporadically exploited a small potash salt amount) and other four are adjacent to the large rock salt deposit at the Gdańsk Bay in northern Poland. All these deposits are now not exploited mainly because of a low prize of imported potash salts, offered from giant potash salt deposits in Belarus, Ukraine or Russia.

Concluding – the resource potential and production of Polish rock salt deposits is enough to prove the national demands but the future direction of their management ought to be construction of safety hydrocarbons cavern storages as well as the waste depositories (also in perspective of atomic power plants location in Poland to prevent the energetic crisis).

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