## Summary of the scientific achievements

**1. First name and surname:**

Grzegorz Czapowski

**2. Scientific degrees:**

a) Master of Sciences in Geology, 1973, MSc Thesis: Lithological-sedimentological characteristics of Miocene sands from the Opatówka Valley. Faculty of Geology, University of Warsaw, supervisor: Prof. Piotr Roniewicz

b) Doctoral degree in Natural Sciences, 1998.
Ph.D. Thesis: Genesis of Zechstein Oldest Rock Salt Formation in the Puck Bay region. Polish Geological Institute, Warsaw, supervisor: Prof. Tadeusz M. Peryt

**3. Professional Experience:**
a) 1976 -1979: assistant at Faculty of Geology, University of Warsaw,
b) 1979 - present: researcher at the Polish Geological Institute (actually - Polish Geological Institute - National Research Institute), Warsaw

**4.** In accordance with **the Article 16 par. 2 of the Act of14th March 2003 on scientific degrees and scientific titles and on degrees and titles in arts (Journal of Laws no. 65, pos. 595 with changes) I indicate 27 publications (see: Zał. 3A, I.B no 1 to 27; Zał. 7; citations shown in bold in the text below with the personal contribution [%] to the papers) under the collective title:**

# Salt rocks and salt deposits in Poland: geology and genesis, resources and their recent and future management

After studies at the Faculty of Geology at University of Warsaw (a master degree of stratigraphy and prospection geology in 1973) I specialized in sedimentology of ancient and modern clastic deposits. Since 1972 I began to use and deepen this experience in the Polish Geological Institute (formerly Geological Institute), in studies of ancient salt deposits on very rich material of well cores and collections of samples. The results of these studies made it possible to to establish a new, original methodology of sedimentary analysis of such special rock types as chlorides (e.g. the characteristics of salt lithofacies first time in Poland distinguished within the Upper Permian evaporites), presented in numerous papers. I finalized this research period with completing Ph. D. Thesis (1998) on interpretation of depositional environment of the Oldest Halite/Rock Salt (Upper Permian; Zechstein) deposits in evaporite basin in the northern Poland.

I'm sure that studies realized to solve the so-called „fundamental" or „cognitive" problems should – especially in a case of natural sciences – offer also the practical application. So my postdoc studies (and the papers reporting their results) focused on both (1) better recognition of genesis of rock salts and other salt types (e.g. zubers and potash salts of Devonian and Permian, Neogene zubers) by usage of interpretation possibilities of the established methodology as well as on (2) practical application of data on occurrence and characteristics of salt formations for estimation salt resources and proposals for their management.

Reported results are grouped here under three **research topics**:

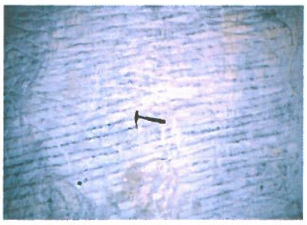
A) *Geology and genesis of salt rocks and salt deposits in Poland* –16 papers presenting results of my „cognitive" studies and contribution to the knowledge of geology and genesis of salt occurrences in Poland,

B) *Resources of salt occurrences and documented salt deposits in Poland* – 6 papers presenting actual knowledge on salt resources in Poland,

C) *Management possibilities of salt occurrences and documented salt deposits in Poland* – 5 papers with opinions on various management options of salt occurrences in Poland.

It is worth to mention that the „cognitive" conclusions given in some of the above mentioned papers are also of practical value so the „interdisciplinary" „interdisciplinary" character of several works and a partially "subjective" their allocation to the distinguished problems. My studies carried on various geological subjects (well cores, mine works) with usage of many analytical methods, required co-operation with many specialists which became co-authors of the majority of papers commented below papers. I prefer the unlimited co-operation of various specialists because in my opinion as such activity is more effective and provides more data and more credible solutions for the studied problems (particularly in a case of such difficult rocks as evaporates) than affords of a single author. Publications in the national periodicals became the significant part of my scientific achievements that enabled a wider group of readers (especially those ones interested in salt exploitation as e.g. geologists and salt miners) to get the newest information on salt rocks characteristics and their interpretations.

The list of my postdoc scientific achievements (from 1998 up to now, as the author and co-author) includes: 59 papers and chapters in scientific monographs, 97 presentations (lectures and posters) with abstracts, 6 popularising papers and 41 expertises and archival works (see – ***Reference list of scientific publications... Zał.*** 3A). I'm made also 37 paper reviews to Polish and foreign scientific journals, I realized 5 scientific grants and I was the leader and the co-organizer of 5 national and international conferences (*op.cit.*).



## Research topic A. Geology and genesis of salt rocks and salt deposits in Poland

This thematic group comprises 16 papers, published in 2001-2013 (in the collective appendix [**Zał.** 7] signed A1 to A16). The presented results refer to three main problems:

1) Lithological and facies development and sedimentary evolution of the Upper Permian (Zechstein; papers signed A1 to A7) and the Miocene (papers signed A8 and A9) salt deposits,

2) The bromine content in salt deposits in their genetic interpretation and as a stratigraphic marker (papers signed A10 to A13),

3) Possibilities to construct 3D models of salt structures (papers signed A14 and A15) and relation between location of salt diapirs and lignite deposits (paper A16).

The first seven of the below listed papers present the results of my sedimentological-lithological studies of evaporites (mainly the Zechstein, subordinarily – the Miocene in age) in Poland.

The paper published 2001 titled "***Geochemical characteristics of rock salt lithofacies of various age from Poland area***" (**Zał.** 7, paper A1; Czapowski G. [*50%*]; in Polish, with English abstract) the first time in Poland applied my established methodology (papers before 1998) of distinguishing fossil salt lithofacies (reflecting various depositional environs of chlorides) to present the principal geochemical characteristics of lithofacies, defined within salt rocks of various age and locations in Poland.

The studied materials came from the well cores and mine works, accessible for facies interpretation and collecting of the chemical data (chemical analyses of furrow and point samples). The studied rocks represent salts of three main evaporite systems in Poland: the Late Permian (Zechstein; 215 wells, 4594 furrow samples and 727 point samples), the Lower (Rhethian) and the Upper (Keuper) Triassic (4 wells, 22 point samples) and the Middle Miocene (Badenian; 12 wells and excavations in two salt mines: Wieliczka and Bochnia; 236 furrow samples and 134 point samples).

After general description of occurrence and development (tab. 1) of distinguished salt facies types (I to VII) I presented (tabs 2 to 4) the intervals (maximum and minimum values) and average content of chemical components (Na, K, Ca, Mg, Cl, Br, Sr, NaCl, $CO_3$, $SO_4$, $Fe_2O_3$, $H_2O$, insolubles in water) and Br/Cl ratio. Most of them are determinated as standard elements for defining usability of salt as a chemical raw material in samples from individual facies but grouped according to the rock age. Differences in content of individual elements in salt lithofacies of various age show relatively constant content (>90%) of NaCl within most of facies except the salt pan one (type IV) of Zechstein PZ1 cycle (34%) and the salt mud flat facies (type VII) of Badenian age (several %). Potassium content in studied facies is generally low (up to 0,3%) and it increases sporadically (along with that of magnesium content) in rocks of Zechstein salt lagoon and pan facies (types III and IV) and the open shallow salt basin one (type II) of PZ1 cycle (up to 9%). The majority of facies of the next Zechstein cycles (from the older to the younger ones) displayed a distinct decrease in bromine content. The share of sulphates (and strontium combined with them) is variable in facies of various ages being slightly increased in rocks of salt lagoon and pan.

Geochemical characteristics of the identified lithofacies (tab. 5) was proposed to be used as a tool for their defining in geological successions on the basis of criteria such as minimum, maximum and average content of analyzed elements. Because of varied factors determining facies deposition, the univocal grouping the set of chemical elements, characteristic for individual lithofacies and enabling its precise definition, appeared not possible but some trends in changes of content of their components were indicated. The basinal salt facies are characterized by a relatively constant content of both ions and compounds and a lithological homogeneity so these deposits are found to be the best as a raw material. More variable lithology and chemical composition of shallow nearshore (salt lagoon and pan and salt-sulphate shoal) and shore (salt-mud flat) chloride deposits reduce their usability as good raw material.

The paper titled ***"Pink salt for production of salt fancy goods – its occurrence, characteristics and exploitation methods in „Kłodawa" Salt Mine"***

(Zał. 7, paper A2; Czapowski G. [40%]; in Polish, with English abstract and captions), published in 2005, presented the first comprehensive description of occurrence conditions, geology and exploitation methods of that so special type of rock salt as so-called *pink salt*, best developed in the Zechstein succession of the Kłodawa salt diapir (figs 1 to 4).

In that paper I defined stratigraphic position of this salt type (tab. 1, with its subdivision into members and their correlation with classic lithostratigraphic subdivision of Zechstein PZ4 cycle and mining divisions). Moreover, I presented its development on the basis of macroscopic analyses and archival data. Chemical characteristics (tabs 2 to 3) of pink salt, based on analysis of samples and archival results, made it possible to distinguish three structural categories of pink salt differing in macroscopic features (colour, crystalline structure, amount, type and occurrence of admixtures – figs 5 to 6). These categories are characterized by decreasing usability for mechanical processing (production of salt fancy goods). The optimal salt type (I category – fig. 5) is developed as an isomorphic to crystalline structureless rock salt with a low content of clay-sulphate admixtures and uniformly dispersed hematite pigment. Further detailed studies are needed to state whether or not that the pink salt is early diagenetic or epigenetic (due to infiltration of lyes with hematite pigment into tectonically fractured rock salt complex during the salt diapir grow).

The next two papers from 2009 presented stratigraphy, development and geochemical characteristics of Zechstein deposits in three wells, drilled in the Góra salt diapir and interpretation of internal tectonic structure of that salt dome.

In the first paper, titled "***Bromine geochemistry and characteristics of Zechstein salt rocks in selected core materials from Góra salt diapir near Inowrocław (Central Poland)***" (Zał. 7, paper A3, Czapowski G. [40%]; in Polish, with English abstract and captions) I presented the lithostratigraphic division and development of Zechstein evaporites (rock and potash salts and zubers of PZ2 and PZ3 cycles - figs 2 and 4) basing on the core profiling from 3 wells. Tredns in changes of bromine content changes in these deposits, supplemented with macroscopic observations (e.g. occurrences of so called secondary *crystal salt*), made it possible to distinguish the core intervals with tectonic duplications in studied sections as well as to locate the axes of internal folds within the salt series (fig. 5).

In the second paper from 2009, titled "***Characteristics and tectonics of Zechstein salt rocks of the Góra salt diapir near Inowrocław on the basis of geochemical–lithological study of selected borehole sections***" (Zał. 7, paper A4, Czapowski G. [50%]; in Polish, with English abstract and captions), I used the formerly obtained data from two wells (G-34 and G-39; figs 3 and 4) and the reinterpreted profile of G-28 well to present the first detailed interpretation of the internal tectonic structure of the Góra salt diapir. The geological section (fig. 5), through central top part of the diapir showed the style and scale of tectonic disturbances, characteristic for salt diapirs. The sketch illustrates the supposed primary structure of upper part of that diapir (fig. 6A). The top part of salt trunk was interpreted as a fold recumbled toward NE and with a nucleus formed of evaporites of the Zechstein PZ2 cycle. These evaporites were found to be surrounded by rocks of the PZ3 and PZ4 cycles, partially "intruding" into the salt trunk. The subsequent uplift and erosion of this diapir removed significant part of this fold and its "envelope" of younger evaporites, giving the salt trunk its present shape (fig. 6B). The proposed interpretation is still a hypothesis only. Anyway, the main aim of that paper was to show a possibility and necessity to interpreting the internal structure of salt domes in

Poland. This problem was hitherto considered superficially in regional works and geological documentations of some salt structures, being recognized (and exploited) by wells for several years.

Initiated by me paper from 2012, titled "***Geology, geochemistry and petrological characteristics of potash salt units from PZ2 and PZ3 Zechstein (Late Permian) cycles in Poland***" (Zał. 7, paper A5, Czapowski G. [45%]), addressed to foreign readers, presented at first time the actual knowledge on occurrence, stratigraphy, development, geochemistry and genesis of primary concentrations of potash and potash-magnesium salts (K-Mg) in Poland. The salts belonged to the Zechstein PZ2 and PZ3 cycles (stratiform occurrences in the Fore-Sudetic area and within 4 salt diapirs: Kłodawa, Inowrocław, Góra and Mogilno – fig. 1). This review was based on archival and literature data and own authors' observations: excavations in Kłodawa diapir (figs 2 and 4) and petrology of thin sections of rocks from both Kłodawa and Inowrocław domes. The paper characterized lithology, geochemistry (tabs 2 and 4), mineral composition (tabs 3 and 5) and petrological features of both K-Mg salt complexes, distinguished as the Older (K2) and the Younger (K3) Potash units.

The most representative (dominant data) the Older Potash (K2) deposits from the Kłodawa dome characterized with a higher content of potassium and magnesium and sulphates of calcium and magnesium (anhydrite, polyhalite, kieserite and epsomite) comparing with the rocks of the Younger Potash (K3) unit. The main potash-bearing mineral there is a sylvine (as a secondary mineral after carnallite transformation) and primary carnallite occurs in a minor amount. Maximum bromine content in halite is higer (500 ppm) in rocks of K3 unit than in those of the K2 one (300 ppm), being the additional differing marker. The reversed mineral and chemical relations and a higher petrological variability are typical for the Younger Potash (K3) rocks. This indicates their lower stage of epigenetic transformation. Some differences were registered in mineral composition and petrological structure of the same age rocks but from other domes: e.g. carnallite content in rocks of the K3 unit from the Kłodawa dome is higher than in its equivalent from the Mogilno diapir but the kieserite content is reversed.

Options of climate interpretation of the Zechstein salt deposits in Poland based on sedimentological and geochemical studies I presented in the paper published in 2013 and titled "***Paleogeographic and palaeoclimate factors of salinity fluctuations in the eastern part of the Late Permian (Zechstein) European Basin: case study from the salt basin in Poland***" (Zał. 7, paper A6, Czapowski G. [70%]). For the first time the registered tendencies of bromine content changes recorded in rock salts (the basic indicator of primary brine concentration) were interpreted as an effect of climatic conditions fluctuations (it is assumed commonly that dry and hot climate favours evaporites generation). Drops of bromine content observed in facially interpreted salt profiles of PZ1, PZ2 and PZ3 cycles, located in various parts of the Zechstein evaporite basin in Poland (figs 2 to 4) I attributed to the higher rain falls dissolving the chloride brines (a humid season). Such effects appeared best traceable in shallow water deposits (salt lagoons and salina facies). Fresh water inputs were less reflected in the more deep-water deposits, analogous drops there I connected with the regional inflows of fresh marine waters into the evaporitic basin. Such inflows resulted probably from eustatic sea level changes in the Panthalassa Ocean or with tectonic widening of straits connecting both basins. Reversed tendency – a rapid increases in brine concentration (bromine content increase), preceding the basin shallowing and accumulation of potash-magnesium salts (e.g. salts of PZ2 cycle – fig. 3) – I interpreted as an effect of limited marine waters input, probably due to tectonic narrowing of straits. Analyses of such changes in selected sections shown that commonly in the „younger" part of each evaporitic cycle the role of rainfalls increased (a more humid period) in comparison to the formerly prevailing „more dry" conditions (a dry period - fig. 5). This suggests the distinct climatic fluctuations in a relatively short time span of Zechstein evaporates accumulation, estimated for maximum 164 Ka years. Moreover during salt deposition of PZ1 and PZ3 cycles the regional inflows of fresh marine waters (result of eustatic sea level changes) took place two times in the PZ1 and three times in the PZ3 cycle. The above mentioned event of a significant drop of sea level took place during the PZ2 cycle, to be followed by appearance o f shallow water facies with accumulation of K-Mg salts.

The paper from 2005 titled "***Polyhalite occurrence in the Werra (Zechstein, Upper Permian) Peribaltic Basin of Poland and Russia: evaporite facies constraints***" (Zał. 7, paper A7, Czapowski G. [10%]) described the occurrence conditions and development of polyhalite concentrations within the Zechstein deposits (PZ1 cycle) in the Peribaltic Syneclise area (nearby the Puck Bay and in areas of the Kaliningrad and Lithuania – fig. 2), basing on analysis of core wells from Poland.

In this work I presented the facies variability of salt deposits (figs 4, 9 to12; tab. 2) in vicinities of the Puck Bay, within which and at their margins occur the polyhalite concentrations. Geochemical determinations (content of bromine, magnesium, calcium and potassium in rock salt – figs 9 to 12) and isotopic (oxygen and sulphur in sulphates - fig. 9 and 13, tab. 3, and chlorine in salt – tab. 4) as well as distribution form and petrology of polyhalite concentrations (figs 5 to 8) shown that polyhalite is a product of anhydrite transformation (after its syndepositional generation from a primary gypsum). This transformation resulted from interaction of concentrated brines (products of evaporation of primary brines) with a sulphate sediment or/and inflow of solutions rich in potassium and magnesium. Such solutions were generated in the shallow salt pans on the sulphate platforms, which top parts and slopes were favourite locations for sulphates polyhalitization (this conclusion is valid in the situation of actual activity to redocument properly the polyhalite occurrences nearby the Puck Bay). The influence of brines rich in calcium, produced by solution of sulphate platform deposits, and inputs of fresh marine brines waters should be also considered here. Similar process could be responsible for the generation of polihalite within the equivalent Zechstein deposits from the eastern part of Peribaltic Syneclise (the Kaliningrad and Lithuania areas) due to the comparable deposits succession (fig. 3) and location of such concentrations on the platform margin as took place in the Poland area.

Two next papers presented results of my sedimentological studies on the Badenian (Middle Miocene) evaporites (Zbudza Formation) in the eastern Slovakia (the area of Miocene East-Slovakian Basin). These deposits are the time equivalent of salt rocks from the Polish part of the Carpathian Foredeep (Wieliczka Formation) and accumulated in the similar environment. Therefore all data on their development and genesis, obtained during such comparative studies, are usefull for interpretation of evaporites on the Polish area.

In the paper from 2003 titled "***Badenian evaporitic-clastic succession in the East Slovakian basin (Zbudza FM, the well P-7)***" (Zał. 7, paper A8, Czapowski G. [30%]) we (together with K. Bukowski) presented the development, basal chemical composition and genesis of the Badenian salt rocks encountered in the P-7 well (fig.

1). At the first time we distinguished three genetic types of these salts: (a) coarse crystalline halites and salt breccias, produced by the mass flows of sediments, (b) fine crystalline salt arenites, being the accumulated halite crystals transported by waving and currents and (c) salt-clay rhythmites, interpreted as the product of alternating drop of suspended clay matter and chemical precipitation of chlorides. Succession of these types in the well profile enabled to distinguish four lithological complexes, generated by subaqual slumps and mass flows (submarine fan deposits) on the basin slope and sediment redeposition from the evaporitic basin margin (an effect of intensive tectonic activity). These events were separated by the periods of calm sediment accumulation from suspension and from chloride brines (rhythmites). The resulted deposits were also transported by waving and currents. Intercalations of claystones with halite clasts ($II^{nd}$ complex) registered the period of maximum refreshment of basin brines and supply of pelitic material from the basin frame. Low bromine content (6-35 ppm) in halite (fig. 2) indicates its generation mainly from the secondary and the diluted by fresh water brines.

Second paper (in 2007), titled "***Sedimentology and Geochemistry of the Middle Miocene (Badenian) Salt-Bearing Succession from East Slovakian Basin (Zbudza Formation)***" (Zał. 7, paper A9, Czapowski G. [30%]) reported the results of continued studies on evaporites of the Zbudza Formation (100-140 m thick) and presented their complete characteristics of development and geochemistry as well as genetic interpretation basing on new data (analyzed profiles of next 5 wells – figs 3 to 4). With K. Bukowski as the co-author I distinguished and interpreted four salt facies types (fig. 5): (A) coarse halitites and salt breccias (proximal deposits of submarine slump fans accumulated from density currents), (B) halite arenites laminated with a clay matter (distal deposits of submarine slump fans and accumulates resedimented by traction currents), (C) rhythmites composed of layers of fine crystalline halite and clay laminae (chemical precipitates from bottom brines and pelitic accumulates dropped from diluted brines) and (D) beds with chevron halite (the product of quick halite precipitation from concentrated brines in shallow conditions). The depositional model of Zbudza Fm evaporites (fig. 10) shown the relations of these facies and enhanced the redeposition process of salts which hitherto was seldom reported in the literature. After lithology, geochemistry and log data five units were defined in the Zbudza Fm profile (fig. 4), which reflected the tectonically controlled cyclicity of evaporitic deposition, comprised two main phenomena: (1) development of slump fans with redeposition of halite and siliciclastics from the shallow water sediments of the basin slope and margin and (2) repeated inputs of fresh marine waters. Development (lithology and structures) and geochemistry (chemical composition – tab. 1, isotopic data – fig. 7 and composition of fluid inclusion in halite – fig. 8) are quite similar to those ones of the age equivalent evaporites (Wieliczka Formation) in the Carpathian Foredeep. They confirm the analogous depositional processes and initiating factors, responsible for their origin in the Poland area.

Four following papers (with my contribution as the co-author) were focused on the problem of bromine geochemistry of the Zechstein salt deposits from Poland.

The paper from 2006 titled "***Bromine in Zechstein mixed clay-salt rocks of Poland***" (Zał. 7, paper A10, Czapowski G. [30%]; in Polish, with English abstract and captions) presents the results of studies on the Zechstein zubers (mixed clay-salt rocks) carried on the cores from the Mogilno salt dome and in the excavations of Kłodawa salt mine within the Kłodawa dome. I described there the stratigraphy and occurrence conditions of the Zechstein zuber deposits in Poland and their development in studied sections (figs 1 to 3). This paper shown that it is necessary to concern in interpretation of bromine content in salts (the accepted indicator of bromine concentration) also the amount of clay matter (clay minerals contain bromine) because the distinct correlation between both components was observed (fig. 4). For salt rocks with high content of clay matter only the bromine content data, determinated in the separated pure halite crystals have to be assumed because its amount detected for the whole rock sample could be false. For the first time it was documented that the studied deposits of the Brownish Zuber (Na3t) unit have formed from the more concentrated brines (higher bromine content) than the younger rocks of the Red Zuber (Na4t) unit.

Following three papers contain results of several years studies – initiated by me and H. Tomassi-Morawiec - focused on finding the specific geochemical marker, enabling to distinguish the Zechstein salt rock units, almost analogous in development but belonged to various evaporitic cycles (salt rocks are devoid of biostratigrafic indexes). The paper from 2007, titled "***Standard bromine profiles for Zechstein salt deposits of Poland: salts of PZ2 (Z2) cycle in Kłodawa salt mine***" (Zał. 7, paper A11, Czapowski G. [35%]; in Polish, with English abstract and captions) describes two profiles with succession of salt rocks of Zechstein PZ2 cycle (units: Na2, Na2+K2 and K2), studied in excavations of Kłodawa salt mine in the Kłodawa dome. Bromine content data from these sections illustrated salinity fluctuations in the primary chloride basin. I described there the stratigraphy, occurrence conditions and development of analyzed salt units (fig. 1) and the results of comparison of bromine profiles. The created profile of bromine content changes within the Older Halite unit (figs 2 to 3), supplemented with data from the Mogilno dome (M-24 well profile), is characterized with a slight bromine increase at the unit bottom. Above in these section the bromine content is almost stable with a slow increase upward but the rapid rise in its top (increased concentration of primary brines in the basin). Comparison of this profile with its time equivalents from the Netherlands and Germany (fig. 4) evidenced the different conditions of salt accumulation during PZ2 cycle. The salt basin in the Netherlands area became several times isolated (several rises of brines concentration) but in the areas of Germany and Poland the salinary basin had a constant marine water input during the most of cycle (relative balance of ratio input/evaporation). Far location of Poland area from the straits, conducting fresh waters from the ocean, resulted there in the earlier salinity increase than in the more close area of Germany.

Next paper from 2008 with the title "***Standard bromine profiles of the Polish and German Zechstein salts (a case study from the Kłodawa and Görleben salt mines)***" (Zał. 7, paper A12, Czapowski G. [35%]; in Polish, with English abstract and captions) included data of former paper, referred to salts of Zechstein PZ2 cycle and presented also the bromine content record for salts of PZ3 cycle, based on their representative sections from the Kłodawa dome and the Görleben dome in Germany. My contribution to this paper – as in the former one – was the description of stratigraphy (tab. 1B), occurrence conditions and development of analyzed salt units of PZ3 cycle (units Na3 and K3). Comparing analysis of bromine content changes within these deposits and their time equivalents from Germany indicated the significant differences of them (figs 4 to 5). The section from Germany registered frequent events of brine solution (bromine content drops), accompanied with sulphates deposition but in the studied profile from the Kłodawa dome such phenomena took place only at the beginning of salt accumulation. Later the evaporation prevailed resulting in a high brine concentration.

The last paper, published in 2009 and titled "***Standard bromine profiles of the Polish Zechstein salts***" (Zał. 7, paper A13, Czapowski G. [35%]; in Polish, with English abstract and captions), summarized the results of studies attempted to create the standard profiles of bromine record in Zechstein rock salts in Poland (cycles PZ1 to PZ4). There were used the former published (salts of PZ2 and PZ3 cycles) results and reinterpreted (salts of PZ1 cycle; data of 80 wells at the Puck Bay, 47 wells from the Lubin-Głogów Copper District [LGOM] and 14 wells from the Żary Pericline and SW part of Fore-Sudetic Monocline) and a quite new data (salts of PZ4 cycle; 2 excavation sections from the Kłodawa dome). My contribution to the paper – as in the former ones – focused on: (a) selection of representative salt profiles for each Zechstein cycle, located in various parts of the Permian basin in Poland, (b) definition of their stratigraphy and occurrence conditions (figs 1 to 4, 7, 11, 15), (c) description of their development (figs 8, 12, 17 to 18; photos 1 to 5) and genesis as well as (d) co-interpretation of bromine record.

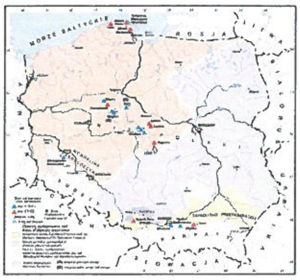
The constructed standard profiles of bromine record in salts of PZ1 cycle from the southern and the northern Poland (fig. 6) and of PZ2 (fig. 10), PZ3 (fig. 14) and PZ4 (fig. 16) cycles from the Poland centre exhibit different trends of bromine content change. The bromine profile of PZ1 chlorides (Na1 unit – fig. 6) characterizes with the initial slow increase of brines concentration (rise of bromine content) but later its longer relative stabilization and at the cycle end the rapid salinity fluctuations were registered. The recorded locally (SW Poland) very low bromine content in halite suggests a salts recycling. Bromine record for rock salts of PZ2 cycle (fig. 10) is tripartite, with the long lower interval of slow increase and its later rapid rise and the short interval of high content, reflecting high brine salinity. The profile top represents the longer period of quick salinity fluctuations (bromine content drop and rises). The standard bromine profile for salts of PZ3 cycle (fig. 14) exhibits the initial quick increase of bromine content (salinity rise) continued with some fluctuations until deposition of potassium-magnesium (K-Mg) salts (K3 unit). The overlying them deposits of Upper Younger Halite (Na3b) unit recorded the gradual decrease of primary brine concentration (bromine content drop). Intervals of high salinity, registered in both profiles, suggest isolation of the evaporitic basin, finalizing with accumulation of K-Mg salts. The bromine profile for salts of PZ4 cycle (fig. 16) shows its initial rapid rise at the profile bottom succeeded by later relative stabilization of content with fine fluctuations and the decrease trend in the profile top. Higher intervals of bromine share in salts of PZ2 and PZ3 cycles compared with those ones of PZ1 and PZ4 cycles (tab. 10) indicated the generally higher concentrations of chloride brines in evaporite basins of first ones. The higher bromine content in zubers of PZ3 cycle than in these ones of PZ4 cycle (figs 17 to 18) but having the almost similar development is a distinctive factor. These standard bromine profiles could be helpful in definition the age (stratigraphic position) of similarly developed salt rocks and to show the possible tectonic duplications within them e.g. in sections from the Góra dome (see – Zał. 7, paper A3).

Two following paper, initiated by me, focused on the problem of modelling the geological structure of salt bodies.

In the first paper from 2007, titled "***Methodology of 3D structure modelling of sedimentary stratiform mineral deposits – a case of the Mechelinki Zechstein salt deposits at the Puck Bay***" (Zał. 7, paper A14, Czapowski G. [38%]; in Polish, with English abstract and captions) for the first time were presented the practical advantages of creation the 3D digital model of raw material sedimentary deposit. To illustrate these options was selected the stratiform rock salt deposit „Mechelinki" at the Puck Bay (fig. 1), for which I described the features of its geological structure (fig. 2) and genesis of salts as well as I prepared the principles of the model data base (fig. 3). Later I verified the elaborated 3D models of various deposit parameters (figs 4 to 6). After these models was possible - the first time for salt deposits - to present the spatial distribution of its various components and features e.g. lithological complexes (fig. 4), salt facies types (fig. 5) and salt series of defined chemical composition (fig. 6). Such models enabled to show to the miners the bodies within the modelled deposit, which have the optimum parameters for salt exploitation or other form of deposit management (the underground gas cavern storage Kosakowo is now build in the commented deposit).

The second paper (published in 2008) titled "***Informatic system of water hazard registration in the Kłodawa Salt Mine in the Kłodawa salt diapir (central Poland)***" (Zał. 7, paper A15, Czapowski G. [20%]; in Polish, with English abstract and captions) presents the creation principles of the 3D digital model of geological structure of the Kłodawa dome. This model has to enable visualisation of water menaces recorded within the dome. As in the former paper I contributed here the basic features of dome tectonic structure (fig. 1), the stratigraphy, occurrence conditions and development of the Zechstein rocks building the dome and I prepared principles of the data base of registered water inputs (figs 2 to 3). The created 3D structural models of the dome parts imaged the spatial distribution of selected salt complexes with the set of mine works (figs 4 to 6) and location of recorded water phenomena (fig. 7). Such model could allow to point the optimal areas for further mining within the dome as well as to avoid the zones with potential hazards e.g. water inputs (by connecting the hazards occurrences with the specific rock lithology or tectonic zones).

The listed paper from 2009 titled "***Halokinetic impact on origin of the Tertiary lignite deposits on the Polish Lowlands***" (Zał. 7, paper A16, Czapowski G. [35%]; in Polish, with English abstract and captions) describes the interesting relations between the salt dome structures and the Cenozoic lignite deposits in Poland. I characterized there the occurrence of Zechstein salt formations and structures in Poland and the parameters of several salt diapirs (fig. 1, tab. 1). Together with J. R. Kasiński we stated the close relation between these diapirs and location and resource parameters (area, resource volume) of 77 documented lignite deposits and its occurrences in the Polish Lowlands. For the first time it was evidenced that over half (41) of these lignites is strictly placed in the salt dome areas (located in the diapr overburden, in the diapir marginal depression and above the diapir) and between the domes (within primary depressions developed between the dome chains). Considering a deposit area the lignite occurrences related with domes became over 69% of whole studied deposits but after their resource volume – over 83% (fig. 6, tab. 3). Halotectonic processes (uplifting and lowering movements), the salt subrosion and karst activity in the dome caprocks highly controlled the accumulation of phytogenic matter, finalized as a lignie deposit (creation of suitable accumulation space or/and remove a part of accumulated sediments by erosion). Several prospective areas for a lignite deposit prospection (except these ones hitherto discovered) were proposed in the surroundings of such salt domes as Damasławek, Inowrocław, Góra, Mogilno, Strzelno, Izbica Kujawska and Kłodawa.



## Research topic B. Resources of salt occurrences and documented salt deposits in Poland

The following thematic group comprises six papers, initiated by me and published in years 2008 - 2013 (in the collective appendix [Zał. 7] signed B1 to B6). These works attempted to present to various readers (in Poland and abroad) a synthetic and actualised (after recognition progress and data supply from the active mines) review of knowledge on geology and on the documented and the potential resources of rock and potassium-magnesium salts in Poland.

The paper from 2008 titled "***Geological recognition status and management perspectives of the Zechstein salt deposits at the Gdańsk Bay"*** (Zał. 7, paper B1, Czapowski G. [40%]; in Polish, with English abstract and captions) shows the simple review of actual knowledge stage on geology of the Permian salts at the Gdańsk Bay (the area from the Puck Bay to the Łeba surroundings) and deposits documented there (fig. 1). I presented there the occurrence conditions, stratigraphy and devoplement of Zechstein evaporites (figs 2 to 4) as well as the prospection history and documenting stage with calculated resources (tab. 1) of three rock salt and four potash-magnesium salt deposits. I also listed their main geological parameters (depth of salt seam top, its thickness and a content of raw mineral – tab. 2). I indicated the facial-thickness variability of chlorides, controlled by sedimentary conditions and by a basin paleobathymetry (thicker salt series with a lower admixture content have accumulated within the deeper part of evaporite basin).

The distinguished two salt lithological types: „pure" rock salt/halite (Na1A) and „contaminated or clayey" rock salt/halite (with a higher content of sulphates and clay matter; Na1B) became the facies varieties, successively deposited within the gradually shallowing basin. Commenting the geology of each rock salt deposit (stratiform, thick sulphate series above and below salt seam as screening horizons, indistinct tectonics) I enhanced their usability to the future (Puck Bay and Łeba deposits) and actually realized (Mechelinki deposit) management as the cavern storages and safe waste disposals. I indicated the location of potassium-magnesium deposits on sulphate shoals in the evaporite basin (fig. 5). Shoal sediments became partially polihalitized by syn- and early diagenetic action of infiltrated brines rich in potassium and magnesium, produced by salt pans developing in the most shallow basin parts.

The other paper from 2008 titled "***The present–day stage of geological knowledge on rock salt deposits in Poland"*** (Zał. 7, paper B2, Czapowski G. [60%]; in Polish, with English abstract and captions) presents for the first time from 1987 a synthetic review of the recognition stage (category and year of deposit documenting, its type as well as the simplified geological structure of most valid deposits) and the management situation (resources, production) of documented rock salt deposits in Poland until 2007 (fig. 1). Volumes of resources and production were reported at 2006 year; my contribution to the paper focused on the Permian rock salt deposits (figs 2 to 4, tabs 1 to 2). I enhanced there the new concept of salt usage as the safe underground cavern storages and waste disposals.

Next paper from 2009, titled "***Salt deposits in Poland – the current state and perspective for management of the resources***" (Zał. 7, paper B3, Czapowski G. [60%]; in Polish, with English abstract and captions), focused on the same problems as the former publication but it acutalized (the stage at 2008) data on resources and production of rock salt deposits in Poland (tabs 1 to 2). These data were attributed to the deposit type: a stratiform, a stratiform-folded and a diapiric ones. The geological structure features of most valid deposits were described (figs 4, 6 to 9). As a new problem I presented there information on the Permian potassium-magnesium salt occurrences in Poland (tab. 3, fig. 3) and commented the management proposals of hitherto non-exploited deposits (e.g. stratiform rock salt occurrences at the Puck Bay and at the nearby of Głogów as cavern storages or waste disposals). I indicated a lack of actual geological recognition of several deposits e.g. the rock salt deposit in the Damasławek dome or the polyhalite deposits at the Puck Bay so is an urgent necessity of their redocumenting before any decision of future exploitation. The simplified version of mentioned paper, addressed to foreign readers, was the work from 2010, titled "***Geology and resources of salt deposits in Poland: the state of the art***" (Zał. 7, paper B4, Czapowski G. [60%]), supplemented with data on the prognostic resources of rock and potassium-magnesium salts in Poland.

The following paper from 2012, titled "***Salt resources in Poland at the beginning of 21st century***" (Zał. 7, paper B5, Czapowski G. [70%]), also addressed to foreigners, presents for the first time the total amount of rock salt (both the Permian and the Miocene in age) and potassium-magnesium salt resources in Poland according their recognition stage in the first decade of XXI century. These volume estimations included both the just documented (anticipated) resources (for 2010 year; figs 1 to 2, tab. 1) and the predicted resources (to the depth of 2km) calculated by PIG-PIB in 2007-2008. These last ones, divided for the prospective and the prognostic categories (after assumed limits of salt seam thickness and the depth of its bottom – tab. 2), were calculated separately for the Permian stratiform rock salts (fig. 3, tab. 3), the salt diapirs (fig. 4, with division for the documented and the preliminary recognized structures [tab. 4] as well as the non-documented forms [tab. 5]) and for the Miocene chlorides (fig. 5, tab. 6). I compared the resource volumes and the areas of rock salt occurrences of different age and. It was shown that the Permian salts predominate in Poland (ca 95% of whole documented resources and ca 100% of the predicted ones – tab. 7); the Miocene salts have a marginal value. More of the anticipated Permian rock salt resources (ca 69%) are located in the salt diapirs (fig. 1, tab. 1) but their predicted resources are connected mainly (96,7%) with the stratiform occurrences (fig. 6, tab. 7). Assuming the production volume of 3.9 mln tones of rock salt per year (average production for the period 2006-2010) their anticipated resources could provide the 26 Ka years of exploitation but the predicted ones – over 500 years at excavation $1/10^6$ of their whole volume. I classified the hitherto calculated resources of Permian potassium-magnesium salts (figs 2 to 3) as the prognostic ones because of their required redocumentation. The total predicted resources of these salts in Poland I calculated for 1,02 bln tones and ca 0,9 bln tones belonged to stratiform deposits (tab. 8).

The last paper (from 2013) titled "***Salt resources of Poland and perspectives of their management***" (Zał. 7, paper B6, Czapowski G. [70%]; in Polish, with English abstract and captions) is the modified version of the former work, addressed to readers in Poland. I enlarged it with the comments on the possible management of rock salt occurrences. In a case of Permian rock salts the several salt diapirs with optimal geological parameters e.g. Goleniów, Damasławek, Izbica Kujawska, Łanięta, Lubień, Rogóźno, Dębina and the part of Kłodawa dome could be considered for location of underground cavern storages or safe waste disposals e.g. mine works in salt seam at Sieroszowice. The deposits of potassium-magnesium salts at the Puck Bay require redocumentation and K-Mg salt occurrences in the Fore-Sudetic area have to be documented to calculate the profitability of their exploitation.

The actualized data on predicted resources of Permian salts in Poland and options of their management, obtained during construction of the maps at scale 1:200 000 of their prospective areas, I presented in the newest paper (2015) titled "***Prospective areas and predicted resources of natural chemical raw materials in Poland presented on the maps at scale 1:200 000 - rock and potash salts and native sulphur***" (Czapowski et. al. 2015; Reference list of scientific publications, Zał. 3A, II.D/16).

## Research topic C. Management possibilities of salt occurrences and documented salt deposits in Poland

The last thematic group comprises five papers, published in the period 2004 - 2012 ((in the collective appendix [Zał. 7] signed C1 to C5). They attempted to show the various options of possible management of salt occurrences in Poland (after current knowledge of their geology): from salt production (underground and solution mining), cavern storages and waste disposals to the protected natural monuments.

The paper from 2004 titled "***Facies analysis of rock salt as the method of management of salt formations***" (Zał. 7, paper C1; Czapowski G. [50%]; in Polish, with English abstract and captions) presented for the first time in Poland the proposals of practical usage of the methods of sedimentary analysis and facies studies of salt rocks to show the options of their management. I introduced the term **„economic salt lithofacies",** defining usability of salt rocks, represented a selected facies, to various forms of management (salt production, storages and disposals). I distinguished four salt economic categories (tab. 2) with a successively lower usability: the I$^{st}$ category (it includes facies of salt deep basin and deep lagoon) with a high usability, the II$^{nd}$ category (facies of salt shallow basin and lagoon) of high to minor usage, the III$^{rd}$ category (saline facies) with high to low usability and the IV$^{st}$ category (facies of salt pan and lake) defined as practically useless. Basing on elaborated paleofacies maps of salt rocks (figs 3 to 4 and 7 to 8) I drew the distribution maps economic salt facies for rock salts of Zechstein PZ1 located on the eastern slope Łeba elevation (fig. 5) and at the Puck Bay (fig. 6) as well as for chlorides of PZ1 to PZ3 cycles in the area of Lubin-Głogów Copper District (LGOM, figs 9 to 11). These maps show the occurrence areas with salts favourable for a defined form of management e.g. the best area for salt production (mining) and location of underground storages at the Puck Bay extends from Bytów, Łeba and Białogarda on the west to Lisewo, Mechelinki and Jastarnia on the east (figs 5 to 6). Similar conditions for such management characterize the SW and NW parts of rock salt seam of PZ1 cycle in the LGOM area (fig. 9) and the NW marginal parts of salt seams of PZ2 and PZ3 cycles in the Bytom Odrzański mining area (figs 10 to 11).

The paper from 2012 titled "***Current geological knowledge on salt structures from the Szczecin region (NW Poland) for perspective location of cavern storages and depositories***" (Zał. 7, paper C2; Czapowski G. [80%]; in Polish, with English abstract and captions) contains data on geological structure and the main parameters (area, depth of salt mirror and of salt body bottom, recognition state etc. – tabs 2 to 3) of 24 salt structures (14 domes and 10 salt pillows – figs 1 to 5, tab. 1), hitherto localized in the Szczecin region. I presented there the opinion – basing on analysis of their geological parameters and possibility of solution brine drop – of construction within these structures the underground cavern storages for hydrocarbons. Such works may be considered as the future, near-state buffer operating storages for purchased gas e.g. from Germany (from the Nord Stream gas pipe). Among all these structures only five domes (Międzyzdroje/Przytór, Wolin-Wicko-Wapnica, Wolin 2, Goleniów and Grzęzno) have the positive geological parameters for construction of storage caverns within (salt top at depth <2 km and salt thickness >150 m). Their location (fig. 1) on the Baltic Sea coast (Międzyzdroje/Przytór, Wolin-Wicko-Wapnica and Wolin 2) and close to the Szczecin Bay (Goleniów and Grzęzno) provides the future safe drop of solution brines. State of their geological recognition of these domes and their surroundings as well as of the analyzed salt pillows (their geological parameters eliminate such form of management) is - except the Goleniów dome – generally low or none so the structures selected for such investment require the new detailed studies.

In two following papers: the first one from 2005, titled "***Non-conventional usage of natural and technical peculiarities of the Kłodawa Salt Mine***" (Zał. 7, paper C3; Czapowski G. [60%]; in Polish, with English abstract and captions) and the second one from 2007 titled "***The possibilities of reuse and utilization of underground voids in „Kłodawa" salt mine***" (Zał. 7, paper C4; Czapowski G. [40%]; in Polish, with English abstract, addressed to the miners, it contains the simplified version of earlier published project of touristic routes) I presented for the first time – as a form of future functioning of salt mines after production stop – the project of usage some excavations in the Kłodawa salt mine as the monuments of unlived nature for educative-touristic purposes. Excavations of this active salt mine, located in the Kłodawa dome, offer as the single place in Poland the direct access to the unique, almost complete, Zechstein rock succession, characteristic for the central part of Permian basin. Also direct observation of various halotectonic phenomena, typical for a salt diapir as well as parageneses of rare salt minerals is invaluable. In the first paper I presented the actualized – according to the official division - stratigraphic profile of Zechstein deposits in the dome (with the proposed additional units and their correlation with mining definitions – tab. 1) and the detailed project of two proposed educative-touristic routes with location and description of individual demonstrative sites (figs 1 to 4). I commented also the formal requirements necessary to establish the legal protection of selected sites as the documenting sites and I listed the procedures obliged to give them such status (e.g. to include in the national catalogue of geosites of the geological heritage such unique places in mine as occurrences of blue halite or polygonal structures within rock salt).

The paper from 2007 titled ***"Underground hydrocarbons storages in Poland: actual investments and prospects"*** (Zał. 7, paper C5; Czapowski G. [49%]), addressed to foreigners, I discussed basing on the literature data the types of underground hydrocarbons storages. I presented the main parameters (e.g. area, location depth, age, permeability and porosity of storage rocks, applied pressures and storage gas volume – tab. 2) of functioned (6 structures) and planned (7 structures) underground gas storages in Poland, located within exhausted oil and gas deposits (fig. 1). Special attention I directed to the Permian salt rocks (the Miocene salts I eliminated because of their lithological and structural variability, intensive tectonic advantage and high water hazards), within which are located active cavern hydrocarbons storages (Mogilno and Góra salt domes). Several domes (7 structures – fig. 2) have the geological parameters (e.g. area, depth of dome and of salt tops, caprock thickness - tab. 3) favouring such usage. To supplement the storage options within geological structures in Poland I characterized also the 7 potential locations (fig. 1, tab. 4) of such storages within the aquifers.

**5. Other scientific achievements**

Simultaneously with the reported studies on salt rocks I continued after Ph.D. Thesis the scientific activity (expressed by publications, presentations of studies results and archive elaborations) concentrated on:

(a) Analysis of depositional environments and their evolution as well as stratigraphy of the Neogene marine (positions: II.A/1; II.D/6, 7 and 15A to C; II.K/12; III.B/3, 4, 47, 48, 50, 52 and 53; III.M/9, 29, 32, 33, 36 – see: **Reference list of scientific publications...** Zał. 3A) and continental deposits (positions: II.D/4 and 15D; II.K/3, 4 and 24; III.B/7, 9, 31, 35, 39 and 47; III.M/7, 14, 30 – see: **Reference list of scientific publications...** Zał. 3A) in Poland,

(b) Development and interpretation of depositional environments of the transition Permian to Triassic deposits in Poland (positions: II.E/2, II.K/7; III.B/26; III.M/4 and 12 – see: **Reference list of scientific publications...** Zał. 3A),

(c) Development and interpretation of depositional environments of the Lower Triassic deposits in Poland (position II.E/7 – see: **Reference list of scientific publications...** Zał. 3A).

## The plan of future research

In 2016 I attempt (as a scientific co-editor and the author of papers) to deliver to the editors the monographic volume of ***Polish Geological Institute Special Papers***. This volume will comprise the papers by Polish and foreign scientists, focused on the comprehensive description of a very unique deposit type as the Permian zubers, best developed and studied in Poland. Moreover I plan in the same time to participate in two papers, presenting the occurrence, development and genesis of continental Miocene deposits from the documented by our PIG-PIB team outcrops and wells, located along the Baltic coastal zone in the Gdańsk Pomerania area.

Grzegorz Czapowski