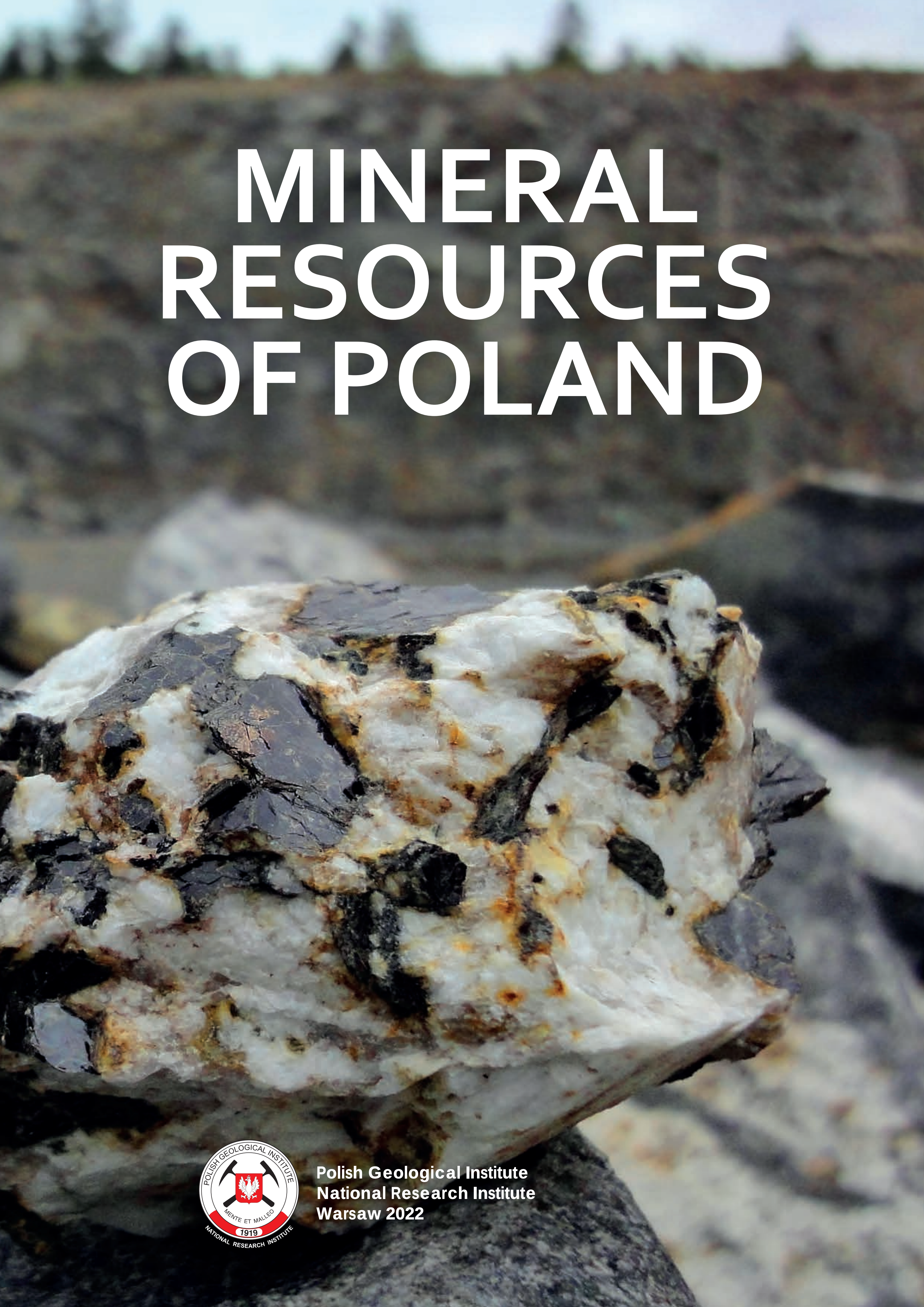
MINERAL RESOURCES OF POLAND



Polish Geological Institute
National Research Institute
Warsaw 2022

MINERAL RESOURCES OF POLAND

Polish Geological Institute
National Research Institute
Warsaw 2022

POLISH GEOLOGICAL SURVEY

Editors: Sławomir Mazurek, Marcin Tymiński, Agnieszka Malon, Marcin Szuflicki

Prepared by: Robert Bońda, Dariusz Brzeziński, Andrzej Chmielewski, Martyna Czapigo-Czapla, Grzegorz Czapowski, Joanna Fabiańczyk, Izabella Gryszkiewicz, Marta Hodbod, Anna Kalinowska, Agnieszka Malon, Sławomir Mazurek, Stanisław Z. Mikulski, Wojciech Miśkiewicz, Maciej Młynarczyk, Jerzy Nawrocki, Sławomir Oszczepalski, Teresa Podhalańska, Lesław Skrzypczyk, Jakub Sokołowski, Michał Sokołowski, Joanna Stawierej, Krzysztof Szamałek, Wojciech Szczygielski, Marcin Szuflicki, Marcin Tymiński, Adam Wójcicki, Krystian Wójcik

Graphic and technical computer elaboration of maps: Joanna Fabiańczyk, Michał Woroszkiewicz, Robert Bońda, Dariusz Siekiera

Translated by: Tomasz Trzpil, Marcin Tymiński, Agnieszka Malon

Calculations and computer works were done in the Economic Geology Department of PGI-NRI using the System of management and protection of mineral resources in Poland – MIDAS

Accepted for printing by
Andrzej Głuszyński, PhD
Deputy Director for the geological survey
Polish Geological Institute – National Research Institute
May 2022

Funded by National Fund
for Environmental Protection
and Water Management

ISBN 978-83-67197-22-9
ISBN (CD) 978-83-67197-23-6

Editorial Board:
Polish Geological Institute – National Research Institute
4, Rakowiecka Street, 00-975 Warsaw, Poland
www.pgi.gov.pl

Layout and typesetting: Anna Kalinowska, Anna Majewska
Cover: Anna Kalinowska (Piława Górna amphibolites and migmatites deposit in the Dolnośląskie voivodeship. Phot. by Dariusz Brzeziński)

Table of contents

PLATES

Foreword

The events that occurred during the preparation of the successive, 6th edition of “Mineral Resources of Poland”, such as the COVID-19 pandemic and the war in Eastern Europe, disrupted raw material supply chains and made it clear that we cannot take access to minerals for granted, while reinforcing the importance of access to locally occurring raw material deposits.

It is our wish that exploration for and documentation of mineral deposits in Poland will expand in the years to come, thus increasing coverage of needs of the domestic and European economies and improving the management of raw materials from local deposits. Easy and preferably free access to geological information is the basis for effective exploration for and mining of mineral resources. Nowadays, however, there is a lot of misinformation circulating and it is increasingly more difficult to find reliable and up-to-date knowledge about the resources of mineral deposits. This publication, together with “The balance of prospective mineral resources of Poland” and “The balance of mineral resources deposits in Poland” (both available in Polish version) provide complete and verified knowledge of Polish mineral resources. Information included in these publications is based on more than 100 years of geological exploration of the territory of Poland by Polish Geological Survey which resulted in discovery of numerous economically important mineral deposits.

It is my sincere hope that this publication prepared by the Polish Geological Survey will bring you closer to the information on mineral deposits in Poland.

Andrzej Głuszyński, PhD
Deputy Director for the geological survey
Polish Geological Institute – National Research Institute

Introduction

Contemporarily, we are witnessing a raw material renaissance around the world. The terms "raw material independence", "diversification of sources and supplies", "domestic resource base" are gaining particular importance. Every country wishes to have their own mineral deposits in order to produce raw materials – to obtain energy and Critical Raw Materials (CRM's), or to exploit such deposits in countries that are stable, safe, and predictable.

In this context we encourage you to familiarize yourself with the resources offered by our country, presented in this 6th edition of the "Mineral Resources of Poland" (MRoP).

For over 70 years, Poland has been documenting new deposits, once financed from the state budget, today practically exclusively by entrepreneurs. Information on these deposits, their geological-mining parameters, resources, mineral quality – are documented in a standardized and uniform manner throughout the country. This has been regulated by law for several decades. Similarly, the geological information and records about mineral resources have been compiled in the same manner over the years. In Poland, basic information on mineral deposits is gathered in databases and is available at https://www.pgi.gov.pl/en/data-bases.html. The basic source of information concerning records of mineral resources is the System of management and protection of mineral resources in Poland – MIDAS (http://www.midas.pgi.gov.pl). The MIDAS system is conveniently accessible to all the interested parties, especially entrepreneurs, geological administration, scientific institutions and state authorities, and is annually presented in the MRoP. At present we have (as of the end of 2020, according to the last "The balance of mineral resources deposits in Poland" – in Polish: "Bilans zasobów złóż kopalin w Polsce") almost 14,500 documented mineral deposits in various stages of development. Some of these deposits are already covered by licenses for mineral extraction (almost 5 thousand of those deposits are being exploited or about to be exploited), and related geological and mining assets (deposits and mines) constitute a significant share in the national economy. In part, the deposit inventory database includes deposits that are already documented (with geologic documentation) but undeveloped. Geological documentation of these deposits is usually found in the resources of the National Geological Archive, maintained by the Polish Geological Institute – National Research Institute (PGI-NRI) and is available to interested entrepreneurs. We also possess knowledge about deposits that were abandoned in the past, which may be worth reactivating today due to the value of the mineral or changes in the economic situation. It is also worth mentioning that archival issues of "The balance of mineral resources deposits in Poland" – starting from 1955 – are available on the website https://www.pgi.gov.pl/bilans-zasobow, in the form of .pdf files.

The layout of this monograph was prepared in such a way as to present, in an orderly and comprehensive way, basic information on deposits, available both for mining enterprises in Poland and foreign entities interested in the Polish mining sector, hence such elements as a glossary of terms, which is extremely important to understand certain differences between Polish nomenclature and nomenclature of other countries, as well as a concise chapter devoted to geological structure of Poland. For the first time the MRoP presents the following chapters: on the economic geology of Poland, on the resources of raw materials critical for Polish and European Union (EU) economies, and on the program of inventorying mine waste for its potential use as a source of secondary raw materials.

Detailed information (in Chapter II) on documented mineral deposits and their resources (at various stages of exploration), included in this publication, is preceded by a noteworthy part (Chapter I) devoted to the exploration and mine licensing system in Poland, fees and taxes connected with licensing and mining, geological information and the rules to access it, and the deposit register system itself. Similar to the previous editions of the MRoP, in this edition, to facilitate your analysis, we present mineral resources of the majority of Polish deposits with reference to the international classification of mineral resources – United Framework Classification for Resources (UNFC).

It is worth stressing that in parallel in Poland the deposit prospects of mineral deposits are being evaluated and results of research works, carried out mainly by PGI-NRI as a research institute and at the same time, the Polish Geological Survey, are being published periodically. The newest, 6th edition of the MRoP, is based (in Chapter II) not only on data on already recognized deposits having data in the form of geological documentation – in accordance with the "The balance of mineral resources deposits in Poland", but what is equally important, it presents results of studies on deposit perspectives in accordance with the newest edition of the "The balance of prospective mineral resources of Poland" (in Polish: "Bilans perspektywicznych zasobów kopalin Polski"). This publication is a combination of knowledge concerning already known mineral deposits with prospects of new discoveries of mineral deposits, which means that it provides unique, comprehensive and most recent knowledge on the state of mineral exploration in Poland.

In Chapter III we supplemented our data with the development status of the work by the Polish Geological Survey pertaining to a circular economy in reference to raw materials, presenting, in a synthetic manner, the results of this work, covering nearly one and a half thousand post-mining anthropogenic accumulations, which, in some areas containing raw materials that can be a secondary source and a valuable supplement to raw materials from primary sources.

The current, sixth, edition of MRoP also contains information on documented, already discovered mineral deposits for the production of Critical Raw Materials (with the Polish CRM list only slightly different from the EU list).

Similarly to previous editions, this publication presents the structure of exports and imports of mineral raw materials in Poland, divided into main groups of raw materials, both in terms of volume and value of trade.

The authors of the chapters and editors of this monograph have tried to thoroughly illustrate all important information – one picture is worth a thousand words. For this reason, in addition to the tables, figures and graphics in the text itself, maps are included at the end of the monograph to graphically represent the most important data and facts provided.

We hope that this collective work by the employees of the Polish Geological Survey will bring you closer to the issues relating to raw material in Poland, and help you make the best investment decisions concerning Polish geological – mineral and mining assets.

Editors
Sławomir Mazurek, PhD
Marcin Tymiński, MSc.
Agnieszka Malon, MSc.
Marcin Szuflicki, MSc.

Abbreviations

List of abbreviations and units of measure and terms used in the book

°C	Celsius degree
µm	micrometer
BC	Before Christ
bn	billion
bnm³	billion cubic meters
bn PLN	billion PLN
bnt	billion tonnes (= 1,000,000,000,000 kg)
Bq	Becquerel
Btu	British thermal unit (equal to about 1,055 joules)
CBM	coal-bed methane
cm³	cubic centimeter
dm³	cubic decimeter
e.g.	for example
EUR	European Union currency (the euro)
g	gram
GML	"Geological and Mining Law" dated the 9th of June, 2011 (Journal of Laws of 2021, Item 1420, unified text; hereafter referred also as the Act)
ha	hectare
HNNG	high-nitrogen natural gas
k	thousand
kg	kilogram
kha	thousands of hectares (= 1,000 ha)
km²	square kilometer
kt	thousand tonnes (= 1,000,000 kg)
LCB	Lublin Coal Basin
LSCB	Lower Silesian Coal Basin
LME	London Metal Exchange
m	meter
M	million
m³	cubic meters
Ma	million ages
Mb/d	million barrels per day
m b.s.l.	meter below surface level
M EUR	million EUR
mg	milligram
MG	aluminous modulus
MH	hydraulic modulus
Mha	million hectares (= 1,000,000 ha)
MJ	mega joules
MK	siliceous modulus
Mm³	million cubic meters (= 1,000,000 m³)
MPa	megapascals
M PLN	million PLN
Mt	million tonnes (= 1,000,000,000 kg)
M USD	million USD
N/Z	overburden to deposit thickness ratio
PLN	Polish currency (in Polish the "Złoty")
ppb	parts per billion
sP	pyrometric cone/pyrocone
t	ton (= 1,000 kg)
Tcf	trillion cubic feet
TOC	total organic carbon
tr oz	troy ounce (= 31.1034768 grams)
USCB	Upper Silesian Coal Basin
USD	United States currency (the dollar)

Glossary

M. Tymiński, A. Malon

UNFC Update 2019 definition according to Annex I and Annex II which form an integral part of UNFC Update 2019 (UNECE, 2020)

Definition of categories and supporting explanations (according to Annex I)

Cat.	Definition	Supporting Explanation
E1	Development and operation are confirmed to be environmentally-socially-economically viable	Development and operation are environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions. All necessary conditions have been met (including relevant permitting and contracts) or there are reasonable expectations that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to the user or market. Environmental-socio-economic viability is not affected by short-term adverse conditions provided that longer-term forecasts remain positive
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future	Development and operation are not yet confirmed to be environmentally-socially-economically viable but, on the basis of realistic assumptions of future conditions, there are reasonable prospects for environmental-socio-economic viability in the foreseeable future
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early stage to determine environmental-socio-economic viability	On the basis of realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future; or, environmental-socio-economic viability cannot yet be determined due to insufficient information. Also included are estimates associated with projects that are forecast to be developed, but which will be unused or consumed in operations

Cat.	Definition	Supporting Explanation
F1	Technical feasibility of a development project has been confirmed	Development or operation is currently taking place or, sufficiently detailed studies have been completed to demonstrate the technical feasibility of development and operation. A commitment to develop should have been or will be forthcoming from all parties associated with the project, including governments
F2	Technical feasibility of a development project is subject to further evaluation	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data acquisition and/or studies may be required to confirm the feasibility of development
F3	Technical feasibility of a development project cannot be evaluated due to limited data	Very preliminary studies of a project, indicate the need for further data acquisition or study in order to evaluate the potential feasibility of development
F4	No development project has been identified	Remaining quantities of product not developed by any project. These are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.)

Cat.	Definition	Supporting Explanation
G1	Product quantity associated with a project that can be estimated with a high level of confidence	Product quantity estimates may be categorized discretely as G1, G2 and/or G3 (along with the appropriate E and F Categories), based on the degree of confidence in the estimates (high, moderate and low confidence, respectively) based on direct evidence. Alternatively, product quantity estimates may be categorized as a range of uncertainty as reflected by either (i) three specific deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50 and P10)[1] are selected. In both methodologies (the "scenario" and "probabilistic" approaches), the estimates are then classified on the G Axis as G1, G1+G2 and G1+G2+G3 respectively. In all cases, the product quantity estimates are those associated with a project. [*continuation on the next page*]

[1] Where P90 means that there is a 90 per cent probability that the actual outcome will equal or exceed this estimate. Similarly, P50 and P10 reflect 50 per cent and 10 per cent probability respectively that the actual outcome will equal or exceed the estimate.

Cat.	Definition	Supporting Explanation
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence	[*continuation*] Additional Comments: The G axis categories are intended to reflect all significant uncertainties (e.g. source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimate forecast for the project. Uncertainties include variability, intermittency and the efficiency of the development and operation (where relevant). Typically, the various uncertainties will combine to provide a full range of outcomes. In such cases, categorization should reflect three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3
G3	Product quantity associated with a project that can be estimated with a low level of confidence	
G4	Product quantity associated with a Prospective Project, estimated primarily on indirect evidence	A Prospective Project is one where the existence of a developable product is based primarily on indirect evidence and has not yet been confirmed. Further data acquisition and evaluation would be required for confirmation. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty should be calculated for the prospective project. In addition, it is recommended that the chance of success (probability) that the prospective project will progress to a Viable Project is assessed and documented

Definition of sub-categories (according to Annex II)

Cat.	Sub-Category	Sub-Category Definition
E1	E1.1	Development is environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions
	E1.2	Development is not environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions, but is made viable through government subsidies and/or other considerations
E2	No sub-categories defined	
E3	E3.1	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations
	E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information
	E3.3	On the basis of realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future

Cat.	Sub-Category	Sub-Category Definition
F1	F1.1	Production is currently taking place
	F1.2	Capital funds have been committed and implementation of the development is underway
	F1.3	Studies have been completed to demonstrate the technical feasibility of development and operation. There shall be a reasonable expectation that all necessary approvals/contracts for the project to proceed to development will be forthcoming
F2	F2.1	Project activities are ongoing to justify development in the foreseeable future
	F2.2	Project activities are on hold and/or where justification as a development may be subject to significant delay
	F2.3	There are no plans to develop or to acquire additional data at the current time due to limited potential
F3	F3.1	Site-specific studies have identified a potential development with sufficient confidence to warrant future testing
	F3.2	Local studies indicate the potential for development in a specific area but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant further testing
	F3.3	At the earliest stage of studies, where favourable conditions for the potential development in an area may be inferred from regional studies
F4	F4.1	The technology necessary is under active development, following successful pilot studies, but has yet to be demonstrated to be technically feasible for this project
	F4.2	The technology necessary is being researched, but no successful pilot studies have yet been completed
	F4.3	The technology is not currently under research or development

Cat.	Sub-Category	Sub-Category Definition
G4	G4.1	Low estimate of the quantities
	G4.2	Incremental amount to G4.1 such that that G4.1+G4.2 equates to a best estimate of the quantities
	G4.3	Incremental amount to G4.1+G4.2 such that G4.1+G4.2+G4.3 equates to a high estimate of the quantities

Definition used in Polish classification system

Resources definitions according to:

- **"Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987);**
- **"Regulation by the Minister of the Environment on a geological-investment documentation of a hydrocarbons field" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 968);**
- **"Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans" (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511).**

Deposit resources ("geological resources" = anticipated economic resources and anticipated sub-economic resources) – total resources of mineral commodity/commodities within deposit boundaries.

The parameter limits that defines a deposit – values of deposit parameters delineating deposit geological boundaries.

Anticipated economic resources ("balance resources") – deposit resources (or part of a deposit) meeting the parameter limits that defines a deposit.

Anticipated sub-economic resources ("sub-balance resources") – deposit resources (or part of a deposit) not meeting the parameter limits that defines a deposit.

Economic resources in place ("industrial resources") – part of anticipated economic resources or anticipated sub-economic resources or – in case of brines, curative and thermal water – exploitable resources, within a designed mining area or detached part of a deposit designed for exploitation, which can be designed for mining according to detailed technical and economic analyses taking into account law requirements, including environmental protection.

Sub-economic (marginal) resources ("not-industrial resources") – part of anticipated economic resources not-classified as economic resources within an area designed for exploitation, which can be designed for mining as a result of technical or economic or law change requirements, including environmental protection.

Extractable resources – part of economic resources in place which is obtained when reducing economic resources by technical losses.

Exploitable resources – crude oil or natural gas resources, which are supposed to be extracted by applying current exploitation technology.

Resources categories definition according to:

- **"Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987).**

Solid mineral commodities

D (inferred resources) – mineral deposit boundaries, geological features and anticipated resources are evaluated on a basis of available geological data, in particular from isolated excavations or natural outcrops, geological interpretation of geophysical measurements. The admissible error of average deposit parameters and deposit resources estimation may exceed 40%.

C_2 (inferred resources) – mineral deposit boundaries are evaluated on a basis of available data from isolated excavations, natural outcrops, interpolation or extrapolation of geophysical measurements; main structural and geological features and tectonics are identified; geological-mining conditions of exploitation are preliminary evaluated; quality of a mineral commodity is evaluated on a basis of regular sampling in the full range of commodity usage. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 40%.

C_1 (indicated resources) – mineral deposit boundaries are evaluated on a basis of available data from exploratory excavations, natural outcrops or interpolation or extrapolation of geophysical measurements; a grade of deposit exploration makes it possible to prepare a Prefeasibility study of economic mining, including the detailed delineation of structural and geological features, tectonics and quality of a mineral commodity in a deposit, geological-mining conditions of exploitation, and allows an assessment of the influence of the intended exploitation on environment. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 30%.

B (measured resources) – mineral deposit boundaries are delineated in details on a basis of the specially carried out exploratory excavations or geophysical measurements, delineation of structural and geological features, correlation of strata, main tectonics features has to be unambiguous, quality and technological properties of mineral commodity should be confirmed by sampling results in pilot-scale tests or commercial scale. The degree of deposit exploration is sufficient enough to elaborate a mine management plan. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 20%.

A (measured resources) – mineral deposit is explored to an extent which allows current planning and carrying out exploitation with a maximum possible rate of resource absorption; delineation of structural and geological features, tectonics, resources on a basis of the opening-up, preparing and mining excavations, type, quality and technological properties of a mineral commodity on a basis of regular excavations sampling and data from the current production is required. The degree of the deposit exploration is sufficient enough to elaborate a mine management plan. The admissible error of average deposit parameters and deposit resources estimation in particular blocks cannot exceed 10%.

Resources categories definition according to:

- **"Regulation by the Minister of the Environment on a geological-investment documentation of a hydrocarbons field" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 968).**

Hydrocarbons

C (inferred resources) – hydrocarbons field boundaries are delineated on a basis of geophysical measurements and geological interpretation; such data makes it possible to plan other work which is necessary to continue field exploration or its exploitation, when there is gas, oil or methane flow from at least one well producing an amount that has economic value or, in the case of multi-horizontal fields, when hydrocarbons saturation of gas and oil horizons is known on a basis of the drilling geophysics logging with gas, oil or methane flow from at least one well producing an amount of economic value. The admissible error of average field parameters and field resources estimation cannot exceed 50%.

B (indicated resources) – results of the implemented geological work are the basis to define a field's geological structure, field boundaries and reservoir parameters of oil bearing and gas bearing formations, as well as their variability in details; such data makes it possible to plan other work which is necessary to continue field exploration or its exploitation, when there is gas, oil or methane flow from at least one well producing an amount that has economic value. The admissible error of average field parameters and field resources estimation cannot exceed 35%.

A (measured resources) – data for category B are defined on a basis of exploitation results. The admissible error of average field parameters and resources estimate is up to 20%.

<u>Definition of mineability assessment stages</u> according to:

- **"Geological and Mining Law" dated the 9th of June, 2011 (Journal of Laws of 2021, Item 1420, unified text);**
- **"Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987);**
- **"Regulation by the Minister of the Environment concerning detailed requirements of a deposit development plan" dated the 24th of April, 2012 (Journal of Laws of 2012, Item 511).**

Mining report – a document is understood as the current documentation of a state of development and exploitation of a deposit during its economic life, including current mining plans. An operator of a mine is generally responsible for preparing said plans. The study takes into consideration quantity and quality of minerals extracted during the reporting time, changes in economic viability categories due to changes in prices and costs, development of relevant technology, newly imposed environmental or other regulations, and data on exploration conducted concurrently with mining.

According to the GML, the mining report is a base for mining plant operation and specifies:
1) an organizational structure of a mining plant, in particular by indicating positions of management and operation supervision;
1a) mining plant boundaries;
2) specific activities to ensure: performing the activity covered by a concession; public safety; fire safety; safety of people residing in a mining plant, in particular concerning work health and safety; rational management of a mineral raw material deposit; environmental protection; protection of building objects; preventing of damage and their repair.

The mining report shall be subject to conditions determined in a concession and a deposit development plan or a development plan for an underground carbon storage facility. In the case of geological work which is not subject of a concession – the report should account the conditions determined in a project of geological work. The mining report shall be prepared covering the period from 2 to 6 years or for the entire planned duration of the operations, if that is shorter.

Deposit development plan (called also Prefeasibility study) – a document provides a preliminary assessment of the economic viability of a deposit and forms the basis for justifying further investigations (detailed exploration and Feasibility study). It usually follows a successful exploration campaign, and summarizes all geological, engineering, environmental, legal and economic information accumulated to date on the project. Various terms are in use internationally for a Prefeasibility studies reflecting a current level of accuracy. The data required to achieve this level of accuracy are reserves/resources figures based on detailed and general exploration, technological tests at laboratory scale and cost estimations e.g. from catalogues or based on comparable mining operations.

According to the "**Regulation by the Minister of the Environment concerning detailed requirements of a deposit development plan" dated the 24th of April, 2012 (Journal of Laws of 2012, Item 511)**, the plan is elaborated within a mining area and shall specify:
1) requirements for rational management of a mineral raw material deposit, in particular through a comprehensive and rational use of the main raw material, as well as of accompanying raw materials, taking into account: a) geological conditions of a deposit occurrence; b) technological abilities and economic factors of exploitation; c) expected method of mining plant decommissioning, protection of resources remaining in a deposit after the end of exploitation, reclamation of an area after mining activities end;
2) environmental protection activities, including exploitation technology ensuring the reduction of the negative environmental impact.

The deposit development plan specifies:
1) economic resources,
2) sub-economic resources,
3) losses within economic and sub-economic resources,
4) extractable resources for solid minerals.

Geological study (geological documentation) – a document is an initial evaluation of economic viability. This is obtained by applying meaningful cut-off values for grade, thickness, depth, and costs estimated from comparable mining operations. Economic viability categories, however, cannot in general be defined from the Geological study because of the lack of detail necessary for an economic viability evaluation. The estimated resource quantities may indicate that a deposit is of intrinsic economic interest, i.e. in a range of economic to potentially economic. The Geological study is generally carried out in the following 4 main stages: reconnaissance, prospecting, general exploration and detailed exploration. The purpose of the Geological study is to identify mineralization, to establish continuity, quantity, and quality of a mineral deposit, and thereby define an investment opportunity.

According to the GML, the document presents the results of geological work, along with its interpretation, definition of a degree of achievement of pursued aims as well as their justification. The geological documentation of a mineral deposit is prepared to determine its boundaries, geological resources, conditions of occurrence and to identify opportunities of exploitation of minerals from a deposit. The documentation shall define in particular: a type, quantity and quality of a raw material, including submission of information concerning accompanying raw materials and useful trace elements co-occurring and present in deposit substances harmful to the environment, as well as a category of exploration; location of a deposit, geological structure, form and boundaries; elements of the environment surrounding a deposit; hydrogeological and other geological-mining conditions of a deposit occurrence; the state of land management within an area of documented deposit; parameter limits that define a deposit and its boundaries. Geological documentation comprises of the following types of documentation:

1) geological – of a mineral raw material deposit, excluding hydrocarbons;
1a) geological-investment – of a hydrocarbon field;
2) hydrogeological;
3) geological-engineering;
4) other than specified in previous points (e.g.: documentation of geological work not resulting in a documentation of resources – either of mineral raw material or underground water; documentation of a borehole aiming the exploration of a deep basement structure, not connected with a mineral raw material deposit documentation; decommissioning of a borehole).

For the preparation of geological documentation for deposits of curative waters, thermal waters and brines, the requirements for hydrogeological documentation shall apply. If a geological documentation shall be the basis for granting a concession, exploration of a deposit occurs in details sufficient to enable the drafting of a deposit development plan. For preparing geological-investment documentation for hydrocarbon fields all of the mentioned above requirements should be met, but also the documentation should specify a way of hydrocarbons field development, exploitable resources, and an optimal variant of rational resources management (regarding the limitation of the environmental hazards).

Definition of geological study stages and a state of deposit development according to:

- **Nieć, 2012 – "Metody dokumentowania złóż kopalin stałych. Część IV. Szacowanie zasobów" (with authors' modifications).**

Prospective resources (D_2) – an indication of probable deposit occurrence. A deposit is expected to occur on a basis of local indicators (geophysical, geochemical anomalies, isolated accumulations of raw material, outcrops, etc.). Possible resources estimated on a basis of general geological data by analogical methodology. An admissible error of deposit resources estimation is not defined.

Prognostic resources (D_1) – a confirmation of raw material occurrence which accumulation may form a deposit. Resources are being assessed on a basis of sparse, rare points of a raw material (deposit) occurrence (outcrops) and on interpretation of geophysical data which enables approximate delineation of a deposit area. An admissible error of deposit resources estimation may exceed 40%.

General exploration – means an identification of a deposit and its preliminary exploration. Data on a deposit come from natural exposures, spare boreholes and mining excavations allowing to preliminary establishing of deposit occurrence conditions and its range. The variant interpretation of a deposit construction, its setting and tectonics is allowed. The data on raw material obtained on a basis of laboratory tests of samples collected from all of evaluative points (exposures, boreholes, excavations). Technological features are assessed on a basis of analogical methodology. In “The balance of mineral resources deposits in Poland”, deposits covered by general exploration are in categories D and C_2 for solid minerals and in a category C for hydrocarbons. Such deposits/fields are marked as “P” in “The balance...”.

Detailed exploration – means deposit exploration to an extent allowing the implementation of its consecutive development stages. Boreholes and mining excavations are located regularly within a deposit area. Deposit occurrence conditions, its form and tectonics can be determined unambiguously. On a basis of samples collected systematically, main raw material types and their distribution within a deposit can be identified. There are also technological, hydrogeological, geological-engineering and gaseous test of a raw material carried out. In “The balance...”, deposits covered by detailed exploration are in categories C_1, B and A for solid minerals and in categories A and B for hydrocarbons. Such deposits/fields are marked as “R” in “The balance...”.

Deposits of operating mines (exploited/developed deposits) – deposits with a valid exploitation concession issued where output is carried out regularly (every year). Such deposits/fields are marked as “E” in “The balance...”.

Deposits exploited temporarily – deposits with a valid exploitation concession issued where output is carried out intermittently. Such deposits/fields are marked as “T” in “The balance...”.

Abandoned deposits – deposits on witch exploitation has been given up. Such deposits/fields are marked as “Z” in “The balance...”.

Major geological features of the area of Poland

J. Nawrocki

General tectonic division and units of the crystalline basement[1]

Three main large tectonic units can be distinguished in Poland (Aleksandrowski, 2020a). They differ from each other in their evolution history and internal structure. The Precambrian Platform (East European Craton) consists of a crystalline basement, which is folded, metamorphosed and intruded by magmatic bodies of the Proterozoic and Carboniferous. Deposits of iron, co-occurring with titanium and vanadium were documented in Mesoproterozoic mafic rocks in the Suwałki region (NE Poland). The crystalline basement of the Precambrian Platform is overlain by a cover of younger i.e. almost exclusively Ediacaran to Quaternary sedimentary rocks. A thick succession of volcanogenic rocks occurs within the Ediacaran column only. The Palaeozoic Platform, partly crystalline, is composed of basement rocks, folded in individual regions during the Neoproterozoic and Palaeozoic orogenies. The cover of undeformed or slightly deformed sedimentary Late Carboniferous and younger rocks overlies both platforms. In southern Poland, the Palaeozoic Platform cover is overlain by the nappes (thrust sheets) of the Mesozoic-Cenozoic Carpathian orogeny that were thrusted over in the Cenozoic.

The Polish crystalline basement consists of a set of Earth crust blocks i.e. terranes differing in internal structure and tectonic evolution. They come from disintegrated Proterozoic orogens, magmatic arcs of the same and younger age, and the Palaeozoic orogens. The terranes of the East European Craton were joined during the Proterozoic. Amalgamation or accretion of terranes to the Palaeozoic Platform took place between the Cambrian and Early Carboniferous. The edge of the East European Craton, where the Palaeozoic Platform terranes docked, is referred to as the Trans-European Suture Zone.

Tectonic structures

In the Sudetes and the crystalline core of the Tatra Mountains, parts of the Cadomian orogen (750–530 Ma) were included in the Variscan orogen. They were also identified under the sedimentary cover of younger rocks of the Upper Silesia and Małopolska regions and under tectonic blocks. In the north-east edge of Małopolska, the Sandomierz Fold Belt was formed near the Cambrian/Ordovician boundary (Aleksandrowski, Buła, 2020a). Late Cambrian granitoid massifs formed primarily in an extensional regime of the Gondwana margin, which occurred in the Sudetes. The Caledonian structures covered by thick Devonian and younger sedimentary rocks have been identified at the edge of the Precambrian Platform, where the Caledonian Pomeranian-Kuyavian Fold Belt was formed in the Late Silurian, due to a collision of Eastern Avalonia and Baltica.

The Variscan structures of the Palaeozoic Platform are mostly hidden under a cover of Cenozoic and Permian-Mesozoic rocks. They are uncovered in the Holy Cross Mountains, the Sudetes and the Tatra Mountains (Aleksandrowski, Buła, 2020b). The internal zone of the Variscan orogen, composed mainly of igneous and metamorphic rocks, is exposed in the Sudetes and their foreland. This zone's structures incorporated into the Alpine orogen also occur at the surface of the Tatra Mountains. The rest of the Palaeozoic Platform is occupied by the structures of the external zone of the Variscan orogen. Carboniferous synorogenic deposits with coal seams fill two intramontane basins i.e. the USCB and the Intra-Sudetic Basin. The coal-bearing Carboniferous strata are also present in the marginal zone of the Precambrian Platform within the Radom-Lublin fold-thrust belt.

[1] Names of structural units presented here were adopted from "Atlas Geologiczny Polski" (Nawrocki, Becker, eds., 2020).

The early Alpine tectonic structures occurring within the Polish Permian-Mesozoic Basin, were developed over the Palaeozoic Platform and created a sedimentary cover up to 10 km in thickness. The tectonic inversion of this basin in the Late Cretaceous-Palaeocene led to the formation of large NW-SE trending tectonic units i.e. the Koszalin-Zamość Synclinorium, Mid-Polish Anticlinorium and Szczecin-Miechów Synclinorium (Aleksandrowski, 2020b). The Permian-Mesozoic deposits that cover the East European Craton have not been folded and form the Mazury-Podlasie Monocline. Two other monoclines with Permian-Mesozoic rocks, the Fore-Sudetic Monocline and Silesian-Cracow Monocline, extend SW of the Szczecin-Miechów Synclinorium.

The youngest tectonic structures in Poland correspond to the formation of the Carpathians and tectonic stress caused by the opening of the North Atlantic. Ahead of the Carpathian thrust belt with predominantly flysch deposits, the Carpathian Foredeep Basin was developed during the Early Miocene. Before its subsidence, it formed part of the Meta-Carpathian Swell. In this peripheral bulge the Holy Cross Mountains, Silesian Upland, Lublin Upland and the Sudetes emerged (Zuchiewicz *et al.*, 2020). On the Fore-Sudetic Monocline and NE of it the tectonic grabens were developed during the latest Eocene–Early Oligocene and later. Some of them are filled by brown coal deposits.

Rocks of the individual stratigraphic systems

Ediacaran rocks, thick up to 500 m, were drilled in northern Poland, Podlasie and the Lublin region. They also occur under the cover of youngest sediments on the Upper Silesia and Małopolska tectonic blocks (Pacześna, Buła, 2020). Most of them are clastic, however in the Podlasie and Lublin regions thick layers of volcanogenic rocks also occur. Metamorphic and igneous rocks of Ediacaran age form the basement of the SW part of the Upper Silesia tectonic block.

Cambrian sedimentary rocks have been documented in the same regions of Poland as the Ediacaran, as well as in the Sudetes (Pacześna *et al.*, 2020). Their maximum thickness c.a. 2–3 km is characteristic for the southern part of Upper Silesia and northern part of the Holy Cross Mountains. At greater depths than reached by existing drill holes, the Cambrian rocks can occur also in north-western Poland and under the Carpathian flysh. In the area of the Peribaltic Syneclise and north of it, the Cambrian sandstones and mudstones contain natural gas and crude oil accumulations.

Ordovician clastic and carbonate deposits form a thin cover (max. up to 400 m) in the northern part of central and eastern Poland. Rocks of this age were also drilled and identified somewhere in Subcarpathia, as well as in the north-eastern part of the Upper Silesian tectonic block (Trela *et al.*, 2020). Their outcrops can be found only in some locations of the Holy Cross Mountains and Sudetes. In the Podlasie region (eastern Poland) the Upper Ordovician shales are enriched with uranium.

Silurian deposits, mainly mudstone, claystone and shale, of various thickness (from tens of meters to over 3 km) have been recognized in deep boreholes in northern, central and eastern Poland, in some parts of the Sudetes and in a few places on the Małopolska tectonic block (Podhalańska *et al.*, 2020b). They occur on the surface in the Holy Cross Mountains and Sudetes only. The Caradocian and Lower Silurian shales in the area stretching from the Lublin region, through eastern Mazovia and western Podlasie, to central and eastern Pomerania, and contain unconventional hydrocarbon accumulations.

Devonian rocks in northern and central Poland occur mainly south-west of the Teissseyre-Tornquist Suture. They have also been drilled in the Lublin region, where they overlie conformably the Silurian beds, and contain crude oil and natural gas. Their maximum thickness exceeds 4.4 km near the city of Lublin. Devonian clastics and/or carbonates are exposed in the Holy Cross Mountains, NE margin of the Upper Silesian tectonic block and in the Sudetes, where some of them have undergone low-grade metamorphism (Miłaczewski *et al.*, 2020). They were mined for copper and lead ore in several places of the Holy Cross Mountains. At present the Devonian limestone and dolomite from the Holy Cross Mountains and Upper Silesia are exploited for construction aggregates and other purposes.

Carboniferous clastic deposits occupy nearly the same areas as the Devonian ones. They are exposed on the surface in Upper Silesia (USCB) and Lower Silesia (Intra-Sudetic and North Sudetic Basins), the Cracow region and the Holy Cross Mountains (Waksmundzka *et al.*, 2020). Their maximum thickness excess 4 km in the western part of the USCB. In this area and in the LCB, the coal seams of Late Mississippian to Pennsylvanian age, are still being mined. The Carboniferous coal-bearing deposits were also exploited in the LSCB. Molybdenum deposits have been documented in several drill cores that penetrated the Late Carboniferous granitoid bodies in the south-eastern part of the Małopolska tectonic block, near the Cracow-Lubliniec Fault Zone.

The earliest Permian (Lower Rotliegend) is represented by the effusive and pyroclastic volcanic rocks that crop out in the Sudetes and near Cracow (Krzeszowice area). They were drilled in many locations in western Poland. The dune, alluvial and playa deposits filled the Upper Rotliegend Basin that developed in western part of Poland (Kiersnowski *et al.*, 2020). The Zechstein marine sediments that filled this basin and adjacent areas are linked with cyclic sedimentation in the epicontinental sea. In the Fore-Sudetic Monocline and North-Sudetic Synclinorium the copper ore deposits, also containing silver, occur at the Zechstein/Rotliegend contact within the cooper-bearing shale. Total primary thickness of the Permian rocks reaches 2.5 km in central and north-western Poland. In some places it is even thicker due to halokinesis. Rock salt is mined from a few salt diapirs (the Kuyavia and Kłodawa regions) and seams (the Legnica and Głogów regions). Potassium salt deposits were found in Pomerania, north of Gdańsk. In western Poland the Zechstein carbonate rocks contain crude oil and natural gas accumulations. The natural gas also can be found in the Rotligend sandstone.

Triassic deposits, with a maximum thickness reaching even 4 km (the Kuyavia region), are represented by clastic and carbonate (mainly Middle Triassic) rocks that were deposited in the Central European Basin (also named the German Basin; Becker, Szulc, 2020). They crop out in Upper Silesia, the Sudetes and the Holy Cross Mountains, and in their Permian-Mesozoic margin. Rocks of similar age also occur on the surface in the Tatra Mountains, where they display some differences with respect to epicontinental deposits of the Central European Basin. The Middle Triassic carbonates of the Silesian-Cracow region contain zinc and lead ore. The Lower Triassic rocks in the area between Olsztyn and Gdańsk are enriched with uranium.

Jurassic deposits, with a maximum thickness over 3.5 km north of Łódź, have been documented in Polish Lowland (Feldman-Olszewska *et al.*, 2020b). They crop out in the Cracow-Częstochowa Upland and in the Permian-Mesozoic margin of the Holy Cross Mountains. Rocks of this age also occur on surface of the Tatra and Pieniny Mountains. The Lower Jurassic of the Polish Lowland is represented by clastic sediments only. The carbonate rocks, in some locations with anhydrites intercalations, predominate in the Upper Jurassic. In some regions of central and southern Poland the Lower and Upper Jurassic rocks contain siderite deposits. Middle and Upper Jurassic sedimentary rocks from the area of the Carpathian Foredeep form reservoirs for hydrocarbons. In central and western Poland the Lower Jurassic clastic rocks are filled by moderate or highly mineralized thermal waters.

Cretaceous deposits have been documented in northern and eastern Poland, and in the NW-SE stretching belt between Szczecin and Tarnów (Plate 1), where their thickness can even exceed 2.5 km (Kuyavia region). They also occur in the Carpathians, Sudetes and the Opole region (Leszczyński, Malata, 2020). Apart from the Carpathians, they crop out in the Lublin Upland, Sudetes, the Permian-Mesozoic margin of the Holy Cross Mountains and along the Vistula valley near Kazimierz. Lower Cretaceous deposits are represented by clastics of different grain-size. The lithological column of the Upper Cretaceous deposits consists of limestone, marl, chalk, gaize and opoka. The Albian sandstone and sand contain phosphorites. Lower Cretaceous rocks contain reservoirs of thermal waters that are either sweet or low mineralized, but not both.

Paleogene and Neogene sedimentary rocks have been documented in almost the entire area of the Polish Lowland. They also occur in the Carpathians, the Carpathian Foredeep where their thickness exceeds 2.5 km, and Roztocze (Gałązka *et al.*, 2020). The Paleogene rocks are represented by marine clastics that contain amber deposits in Eastern Pomerania and the northern part of the Lublin region. The Neogene of the Polish Lowland consist of terrestrial sediments, in many places with thick brown coal seams. Rocks of this age, which are located in the Outer Carpathians and the Carpathians Foredeep contain hydrocarbons, rock salt and sulfur.

Quaternary deposits with a maximum thickness c.a. 300 m in northern Poland, are represented mainly by glacial, glaciofluvial, aeolian, alluvial, lacustrine and marine clastic rocks (Gałązka, Nowacki, 2020). Apart from the mountains and parts of uplands, the cover of Quaternary deposits is continuous. The organic-rich peats and gyttja deposited during the interglacial period have also been documented in many places throughout the Polish Lowland. Most of ceramic clay and natural aggregate deposits in Poland are Quaternary in age.

CHAPTER I

Formal and legal aspects of geological and mining activities

1. Geological and Mining Law

S. Mazurek, M. Młynarczyk, K. Szamałek

The mineral law in Poland is much formalized in contrast to mineral regulations in the common law countries. Therefore in this chapter we present only the most important regulations of the Polish mineral law. Currently, the geological and mining activity in Poland is regulated by the "Geological and Mining Law" adopted on the 9th of June, 2011 (Journal of Laws of 2021, Item 1420 – unified text – hereinafter referred as the Act). In addition, some of the issues fall within the scope of regulation by other laws, such as the environmental protection, mining waste law, etc. The evolution of the Polish legal system in the fields of geology and mining over the last decades was presented by Szamałek and Młynarczyk (2017).

The GML (the Act 2011) defines the terms and conditions for undertaking, implementing and completing activities in the scope of:

- geological work,
- minerals extraction from deposits,
- non-reservoir storage of substances in the subsurface,
- storage of waste in the subsurface,
- storage of carbon dioxide in the subsurface.

Additionally, the Act sets out requirements for the protection of mineral deposits, groundwater, and other components of the environment as they relate to the above-mentioned activities. The Act also determines the rules, exercising supervision and control over the activities specified in the Act. The Act also pertains to:

- construction, development and maintenance of drainage systems of liquidated mining plants;
- excavation work carried out in closed underground mining plants, mainly for touristic, curative and recreational purposes;
- underground work conducted for scientific, research, experimental and training purposes for the needs of geology and mining;
- tunneling when using mining techniques;
- decommissioning indicated above entities, equipment and installations.

The Act shall not apply to:

- the use of water (regulated by the separate law/act);
- the execution (beyond the mining areas) of pits and boreholes to a depth of 30 m in order to use geothermal heat;
- the execution (beyond the mining areas) of pits and boreholes to a depth of 30 m in order to use groundwater in amounts up to 5 m^3;
- research and teaching activities carried out without the execution of geological operations;
- acquisition of samples of minerals, rocks and fossils for scientific, collecting and teaching purposes carried out without performing mining operations;
- carrying out operations related to artificial supplying of the shoreline zone with sand coming from sea floor sediments of the maritime areas of the Republic of Poland;
- aggregate extraction to the extent necessary to complete urgent work to prevent flooding during a natural disaster;
- determining the geotechnical conditions of building foundations without performing mining operations.

The Act concerns mineral deposits, however water is excluded from mineral resources. Only curative and thermal water as well as brines are treated as minerals resources.

In Poland the geological profession is regulated by law (the Act). The Act describes that a person undertaking the operations consisting of performing, supervising and directing geological work should have the qualifications specified by the Act. The categories (total of 10) specified in the Act are as follows: economic geology (3 types), hydrogeological (2 types), engineering-geological (2 types), geophysical, geological mapping, and directing of field geological work. The certification of geological qualifications is issued by the Minister of Climate and Environment (for 9 types) and by the voivodeship marshal (1 type). The candidate, who would like to receive the certificate of qualified geologist, should have adequate education, professional practice and ought to pass the exam.

2. Ownership of mineral resources

S. Mazurek, M. Młynarczyk, K. Szamałek

The Polish legal system determines two types of mineral deposit ownership: state ownership (State Treasury) and land ownership. The state ownership concerns mineral deposits described as covered by the so-called mining ownership.

The mining ownership (state ownership) concerns hydrocarbon, hard coal, and methane deposits accompanying hard coal, lignite, native metals, ores of radioactive elements, native sulfur, rock salt, potassium salt, potassium-magnesium salt, gypsum and anhydrite, gemstones, rare earth elements and noble gases, and metal ores (with the exception of soddy iron ores). The state ownership of the above-mentioned minerals does not depend on the place of their occurrence. The state ownership also covers deposits of curative and thermal water and brines. The deposits of minerals not indicated in the Act belong to the land owner. The Act introduces very important rule of so-called mining usufruct (term adequate to a mining lease) which concerns only minerals owned by the State. In connection with this rule, the minister responsible for the environment on behalf of the State Treasury, with the exclusion of other persons, can benefit from the subject of mining properties or dispose of the right of the exclusively state-owned minerals by establishing the mining usufruct. The regulations concerning the mining usufruct do not apply to geological work, which do not require a concession. The establishment of mining usufruct shall be done by way of written agreement and requires paying a determined remuneration to the State Treasury. The remuneration to the State concerns both geological and mining activities being realized in the rock mass. The mining usufruct agreement enters into force at the date of receiving a concession. The establishment of mining usufruct may be preceded by a tender process, in particular when more than one entity is striving to obtain it. In the case of hydrocarbons the establishment of mining usufruct is obligatorily preceded by a tender process for said concession.

In case of a concession withdrawal, expiration or loss of its validity, regardless of reason, mining usufruct expires.

The entity who, as a result of geological work, explored the mineral deposit (excluding hydrocarbons), being the subject of mining ownership (State Treasury ownership) and documented it sufficiently to enable the preparation of a deposit development plan, as well as obtained a decision approving the geological documentation of the deposit on the basis of a prospecting and/or exploration concession, may demand the establishing of the mining usufruct for its own benefit, with priority over other parties. The priority right shall expire 3 years from the notification date of the decision approving geological documentation. The entity which has priority rights can declare a willingness to receive the mining usufruct agreement, in which case that agreement ought to be established no later than 3 months from the date of declaration.

3. Concession system

S. Mazurek, M. Młynarczyk, K. Szamałek

The Polish law (the Act) requires concessions for the following activities:

- prospecting or exploration of mineral deposits owned by the State Treasury, excluding hydrocarbon deposits;
- prospecting or exploration structures and rock complexes for underground storage of carbon dioxide;
- exploiting minerals from deposits;
- prospecting or exploration or extraction of hydrocarbons deposits;
- non-reservoir underground storage of substances;
- underground storage of waste;
- underground carbon dioxide storage.

A concession is granted for a period no shorter than 3 years and no longer than 50 years, unless an entity has explicitly submitted a concession application for a shorter period. It is necessary to underline that only prospecting and exploration of state-owned deposits requires concessions. In the case of prospecting and exploration of deposits owned by a land owner, it is necessary to have a plan of geological work approved by a geological administration authority. In both cases i.e. state-owned minerals, as well as land-owned minerals, it is obligatory to obtain a concession for mineral extraction (regardless of extraction method – wells, open pits, underground mines).

There are three concession authorities: the minister responsible for the environment (assisted by Poland's Chief Geologist), the voivodeship marshal (assisted by a chief voivodeship geologist) and the county mayor (assisted by a county geologist). The responsibilities of these concession authorities are divided as follow:

- the minister has right to grant concessions for prospecting, exploration and extraction of state-owned minerals (also including all minerals occurring in the Polish maritime zone), underground storage of waste and substances;
- the county mayor has right to grant concessions for extraction of minerals belonged to land property when:
  - the area of documented deposit is less than 2 ha,
  - annual mineral extraction not exceed 20,000 m^3,
  - mining by open pit method without explosive materials;
- the marshal has right to grant concessions for other activities than those listed above.

A concession authority has the right to refuse a concession. The GML describes the cases in which it is possible to refuse a concession. The concession authority refuses a concession, for example, if the intended activity is detrimental to public interest, particularly related to national security or environmental protection, including the rational management of mineral deposits. This can also occur in a case where the intended activity would prevent the use of real estate in accordance with the purpose specified by the local urban spatial development plan or by the separate regulations, and in a case of absence of local urban spatial development plan – would prevent the use of real estate as defined in the study of conditions and directions of spatial management of the municipality.

The concession shall specify:

- the type and manner of performing the intended activity;
- the boundaries of an area where the intended activity is to be performed;
- the expiration date of the concession;
- the commencement date of activities specified by the concession and, if necessary, the conditions that commence the activity.

The concession may stipulate other requirements on the performance of activities covered by the concession, in particular general safety and environmental protection.

A concession for prospecting/exploration of minerals, excluding hydrocarbon deposits describes also next requirements:

- the purpose, scope and nature of the intended geological work (including geological operation) and the minimal category (degree) of the deposit identification;
- the scope and schedule for the transfer of geological information and samples obtained as a result of implementing geological work;
- the amount of money for the remuneration of the activities specified in the concession.

The maximum area covered by a single concession for prospecting/exploration is 1,200 km^2.

The concession for mineral extraction from a deposit may also determine the minimum level of reserve extraction from the deposit during the mine's lifetime, the operations which are necessary for the rational development of the project, and the conditions for injecting water into the rock mass.

4. Geological and mining supervision

S. Mazurek, M. Młynarczyk, K. Szamałek

The Polish geological administration is comprised of the minister responsible for the environment – currently the Minister of Climate and Environment (assisted by Poland's Chief Geologist), the voivodeship marshals (assisted by the chief voivodeship geologist) and the county mayor (assisted by a county geologist). These administration authorities are independent of each other as the minister represents the government, and the marshal and county mayor represent local government. The responsibilities are divided among geological administration as follows: the minister is responsible for approving geological work projects and geological documentation concerning:

- state-owned mineral deposits;
- the Polish maritime zone;
- regional hydrogeological research;
- determining hydrogeological conditions in connection with planning drainage of mineral deposits and injection of drainage water into the rock mass;
- determining for hydrogeological conditions in connection with establishing underground water reservoir protection areas;
- determining the hydrogeological and engineering conditions for non-reservoir underground storage of substances and underground waste disposal;
- determining the hydrogeological and engineering conditions for prospecting/exploring of underground carbon dioxides storage;
- the regional study of the geological structure of the country;
- regional geological cartography work;
- deep drill holes for recognizing deep geological structures, unrelated to the mineral deposits documentation;
- hydro engineering buildings with a dam height exceeding 5 m.

The county mayor is responsible for issues related to approving geological work projects and geological documentation concerning:

- mineral deposits belonging to land owner if the area up to 2 ha is dedicated for opencast mining with an annual output up to 20,000 m^3, and without the use of explosives;
- intakes of groundwater with predicted or fixed resources not exceed 50 m^3/h;
- engineering and geological research carried out for the needs of the county's spatial development and for the conditions of constructing of foundation systems (excluding inter-voivodeship linear investments);
- buildings drainage of capacity not exceeded 50 m^3/h;
- geological work dedicated to geothermal heating systems;
- hydrogeological conditions related to the planned implementations of projects that may adversely affect underground water reserves, including their contamination; regarding the projects classified as significantly affecting the environment, for which the obligation to report on the impact of the project on the environment may be required; with the exception of the projects that may adversely affect curative water resources.

Responsibilities not described as obligations of the minister, or the county mayor, belong to voivodeship marshal.

The duties of Polish Geological Survey (in Polish: państwowa służba geologiczna – PSG) are described in Art. 162 of the Act, and based on Art. 163 of the same Act are ascribed to and performed by the Polish Geological Institute – National Research Institute (PGI-NRI).

The mining authorities are composed of the President of the State Mining Authority and directors of the district mining offices. The structure of mining authorities is vertical, with the district mining offices being supervised by the President of State Mining Authority.

5. Financial regulation

S. Mazurek, M. Młynarczyk, K. Szamałek

The geological and mining activity is charged to a number of taxes, levies and other financial duties. They include general taxes, such as income tax (CIT, PIT), VAT, local taxes, social insurance fees, etc. Financial instruments are introduced by the Act (Tab. 5.1). They concern concession fees (production activity is not required for concession fees to occur), exploitation fees (royalties), fee for establishing of mining usufruct (mining lease). The payment for establishing of mining usufruct is determined by a representative of State Treasury (this may be the minister responsible for the environment or a voivodeship marshal).

The concessioner (holding the concession for prospecting/exploring of mineral deposits) shall pay a total fee, which is based on the area of land covered by the concession, multiplied by the rate charged per square kilometer of a particular mineral. The formula for calculating the concession fee is as follows:

$$C_f = S \cdot P_c$$

where:
C_f – total concession fee [PLN]
S – the area covered by the concession [km²]
P_c – rate per square kilometer determined for type of mineral [PLN/ km²].

The current rate for prospecting works for hard coal and uranium ores is PLN 624.71/km², for lignite PLN 241.91/km², for hydrocarbons PLN 234.88/km², and for other minerals covered by mining property (state ownership) PLN 124.98/km². The rate charged for exploration and common prospecting and exploration activities is calculated as double the rates mentioned above. The calculated fee is payable within 14 days from the day the concession becomes final. Individual rates are also calculated for underground storage of waste and other substances.

An entrepreneur who obtained a concession for mineral extraction pays a charge to be established as the product of its rate and quantity for the mineral extraction, with the anticipated economic and anticipated sub-economic resources in the trading period.

The formula for calculating an extraction fee is as follows:

$$E_f = R_c \cdot V$$

where:
E_f – total extraction fee [PLN]
R_c – rate of charge determined for type of mineral, the rates indicated in the Appendix to the Act [PLN/m³, t, g – respectively]
V – extraction in half year period [m³, t, g – respectively].

The rates being charged for particular types of minerals are determined by the annex to the Act. The rate charged for extraction amounts to 50% for accompanying minerals and useful substances extracted from hydrocarbons. The current rates for extraction of some select minerals is as follows: barite – 6.51 PLN/t, basalt – 1.29, gypsum – 2.07, kaolin – 3.64, Zn-Pb ores – 1.41, Cu ores – 3.80, hard coal – 2.61, lignite – 2.07. Additionally, an entrepreneur who obtained a concession for the extraction of mineral deposits or for underground waste storage of substances and carbon dioxide, must create a special fund for the future closure of the mining plant (Art. 128 of the Act). The calculation of the contribution for special closure fund differs for open-pit mining and for underground mining. In the case of underground mining,

Table 5.1. The types of special financial instruments related to geological and mining activities

The type of financial taxes and levies introduced by the Act
Fee for establishing the mining usufruct
Concession fee
Extraction fee
Additional fee
Increased fee
Remuneration for using of geological information
Obligatory contribution to a mining plant closure fund
Fines

the contribution is equivalent to no less than 3% of asset amortization. For open-pit mining the contribution is equivalent to no less than 10% of the extraction fee.

The activity performed in flagrant violation of the conditions described in the concession or the approved plan for geological work shall be subject to additional fees. An additional charge is determined by the concession authority and could be up to five times higher than regular fees.

By contrast, the activity performed without a required concession or without an approved plan of geological work is subject to an increased fee. The authority responsible for determining of increased fee is the Minister of Climate and Environment or the mining authority, respectively. For example the increased fee is determined at 50,000 PLN for each square kilometer encompassing the illegal activity (prospecting/exploring of state-owned minerals). The increased fee for illegal extraction is calculated as 40 times of regular extraction rate (multiplied by the amount of extracted mineral).

In Part X of the Act is presented the system of fines determining. The President of the State Mining Authority is responsible for imposing a financial penalty on an investor who violates the GML.

The use of geological information (geological, seismic profiles) also comes with fee. Any investor who intends to use geological information belonging to the State Treasury, to prepare an application to the concession for exploitation or for approval of geological documentation pays a remuneration fee calculated according to the rules contained in the disposition prepared by the Minister of Climate and Environment.

6. Classification of mineral resources

A. Malon, M. Tymiński

6.1. United Nations Framework Classification for Resources (UNFC Update 2019)

6.1.1. UNFC Update 2019 – history

During the 1990s, the Economic Commission for Europe (ECE) took the initiative to develop a simple and uniform system of classifying and reporting reserves and resources of solid fuels and mineral commodities. As a conclusion to these reports the United Nations Framework Classification for Reserves and Resources for Solid Fuels and Mineral Commodities (UNFC-1997) was created. Then, in 2004, the system was extended to also apply to hydrocarbons and uranium (UNFC for Fossil Energy and Mineral Resources 2004). In order to facilitate the worldwide application of the Classification, the ECE Committee on Sustainable Energy directed the Ad Hoc Group of Experts on Harmonization of Fossil Energy and Mineral Resources Terminology (now the Expert Group on Resource Classification). The Group is comprised of the United Nations' Member States, international organizations and the United Nations Regional Commissions. The effect of the efforts was a simpler and revised version of the UNFC, called UNFC-2009, prepared in 2013. Moreover, specifications and rules of application were developed. The active and substantive contributions to all these efforts by the Polish representatives (I. Grzybek, M. Nieć, S. Przeniosło, M. Piwocki, K. Szamałek) should be emphasized. The renewable energy (geothermal) and injection projects were included into the UNFC in 2016, bioenergy – in 2017 and anthropogenic resources – in 2018.

The United Nations Framework Classification for Resources (UNFC) Update 2019 is an update of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 incorporating Specifications for its Application (ECE Energy Series 42 and ECE/ENERGY/94) that was issued at the end of 2013 (UNECE, 2020). The integrated renewable resource classification (including geothermal, bioenergy, solar, wind and hydropower) was constructed in 2020.

In September 2017, the ECE Committee on Sustainable Energy, during its twenty-sixth session, approved the name change of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009, to the **United Nations Framework Classification for Resources (UNFC)**.

The Expert Group on Resource Management during its tenth session recommended that the language of the UNFC be revisited and improved to be inclusive of the full spectrum of various commodities and stakeholders of the UNFC. The updated version of the UNFC is intended to satisfy the requirements of different resource sectors and applications, as well as to be more aligned with the sustainable management of resources called for by the 2030 Agenda for Sustainable Development. The key changes, including the normalization of the text, make the UNFC applicable for all resources. **The update does not change the classification system and hence does not impact the current users of the UNFC.** This updated text is intended to make application easier for users of the UNFC (UNECE, 2020).

The UNFC is a resource project-based and principles-based classification system for defining the environmental-socio-economic viability and technical feasibility of projects to develop resources. It should be emphasized that the terms "resource" and "resources" are not defined in the UNFC, because they have specific, but different, definitions in different sectors – these terms are used by the UNFC in a generic sense. The UNFC provides a consistent framework to describe the level of confidence of the future quantities to be produced by the project (UNECE, 2020). All types of sources – solar, wind, geothermal, hydro-marine, bioenergy, injection for storage, **hydrocarbons, minerals (solid)**, nuclear fuels and **water** – are the feedstock to resource projects from which products can be developed. A Project, in the context of the UNFC, is defined as development or operations which provide the basis for environmental, social, economic and technical evaluation and decision-making. The Project plan may be detailed or conceptual (in the case of long-term national resource planning), but should be sufficiently detailed to allow an appropriate assessment for the stakeholders needs at a defined level of maturity (UNECE, 2020).

The UNFC has been designed to meet, to an extent, the needs for applications pertaining to: policy formulation based on resource studies, resources management functions, corporate business processes, financial capital allocation.

6.1.2. UNFC – basic rules

The UNFC is a principles-based system in which the products of a resource project are classified on the basis of the three fundamental criteria of (UNECE, 2020):

- environmental-socio-economic viability (E) – this set of categories (the E-axis) designates the degree of favorability of environmental-socio-economic conditions in establishing the viability of the project, including the consideration of market prices and relevant legal, regulatory, social, environmental and contractual conditions;
- technical feasibility (F) – this set of categories (the F-axis) designates the maturity of technology, studies, and commitments necessary to implement the project. These projects range from early conceptual studies, through to fully developed and operating projects, and reflect standard value chain management principles;
- degree of confidence in the estimate (G) – this set of categories (the G-axis) designates the degree of confidence in estimating of the quantities of products resulting from the project.

Combinations of these criteria create a three-dimensional system (Fig. 6.1.1). Categories (e.g. E1, E2, E3) and, in some cases, sub-categories (e.g. E1.1) are defined for each of the three criteria.

The Categories and Sub-categories are the building blocks of the system, and are combined in the form of "Classes". A Class is uniquely defined by selecting from each of the three criteria a particular combination of a Category or a Sub-category (or groups of Categories/Sub-categories) – since the codes are always quoted in the same sequence (i.e. E; F; G) the letters may be dropped and just the numbers retained. Therefore, the numerical code defining a Class is identical in all languages using Hindu-Arabic numerals (UNECE, 2020). Thereby, the UNFC can be visualized in three dimensions (as shown in Figure 6.1.1), or represented as a practical two-dimensional abbreviated version, as shown in Table 6.1.1.

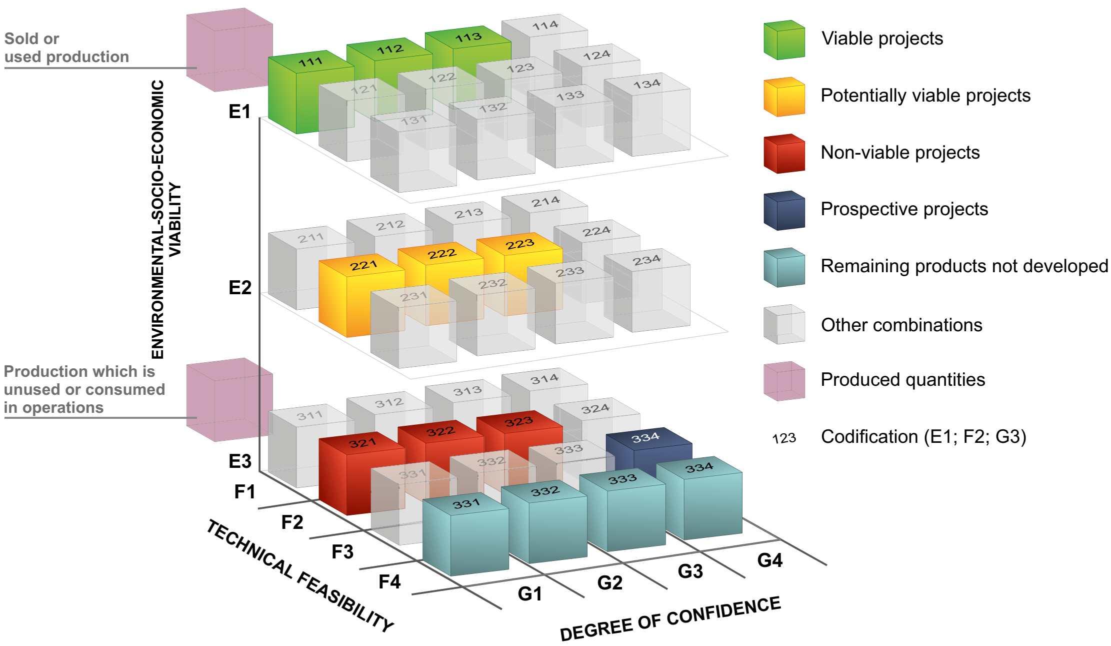


Figure 6.1.1. UNFC Update 2019 – categories and example of classes (UNECE, 2020)

Table 6.1.1. Abbreviated version of UNFC, showing Primary Classes (UNECE, 2020)

	Produced	Sold or used production			
		Production which is unused or consumed in operations[1]			
		Class	Minimum Categories		
			E	F	G[2]
Total Products	The project's environmental-socio-economic viability and technical feasibility has been confirmed	Viable projects[3]	1	1	1, 2, 3
	The project's environmental-socio-economic viability and/or technical feasibility has yet to be confirmed	Potentially viable projects[4]	2[(5)]	2	1, 2, 3
		Non-viable projects[6]	3	2	1, 2, 3
	Remaining products not developed from identified projects[7]		3	4	1, 2, 3
	There is insufficient information on the source to assess the project's environmental-socio-economic viability and technical feasibility	Prospective projects	3	3	4
	Remaining products not developed from Prospective projects		3	4	4

[1] Future production that is either unused or consumed in the project operations is categorized as E3.1. These can exist for all classes of recoverable quantities.
[2] G categories may be used discretely, or in cumulative scenario form (e.g. G1+G2).
[3] Estimates associated with Viable projects are defined in many classification systems as reserves, but there are some material differences between the specific definitions that are applied within different industries and hence the term is not used here.
[4] Not all Potentially viable projects will be developed.
[5] Potentially viable projects may satisfy the requirements for E1.
[6] Non-viable projects include those that are at an early stage of evaluation in addition to those that are considered unlikely to become viable developments within the foreseeable future.
[7] Remaining products not developed from identified projects or Prospective projects may become developable in the future as technological or environmental-socio-economic conditions change. Some or all of these estimates may never be developed due to physical and/or environmental-socio-economic constraints. This classification may be of less value to renewable resource projects but can still be used to indicate the amount of unrealized potential. It is emphasized that the remaining products are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.).

With the exception of past production that may have been measured, quantities are always estimated. Therefore, there will be a degree of uncertainty associated with these estimates. The uncertainty is communicated either by quoting discrete quantities with decreasing levels of confidence (high, moderate, low) or by generating three specific scenarios or outcomes (low, best and high estimates). A low estimate scenario is directly equivalent to a high confidence estimate (i.e. G1), whereas a best estimate scenario is equivalent to the combination of the high confidence and moderate confidence estimates (G1+G2). A high estimate scenario is equivalent to the combination of high, moderate and low confidence estimates (G1+G2+G3). Quantities may be estimated using deterministic or probabilistic methods (UNECE, 2020).

Classifications often need to be adapted to national or local needs. Modifications of this nature should be checked for consistency with the unabbreviated UNFC and other applications in use. For transparency, variances from the UNFC should be documented when adapting it.

6.2. Polish classification system and the UNFC Update 2019

A proposal for comparing the UNFC and the Polish classification systems of geothermal energy (based on the McKelvey diagram) was published (Hajto, 2016, 2018). A comparison of the Polish hydrocarbon resources classification system with the PRMS, the UNFC and applied to unconventional (shale gas) resources was also presented (Nieć, 2016).

The Polish classification of the mineral resources is based on similar rules as the UNFC Update 2019 and in making some assumptions respective classes of UNFC can be identified between the two. Some of them are not formally used in Poland – for example the exploitable resources of solid raw materials (Nieć, 2010a). The UNFC Update 2019 distinguishes four grades of deposit exploration: G1, G2, G3, G4 and these grades compare to the Polish categories: A+B, C_1, C_2, D and D_1–D_3 (Tab. 6.2.1).

Considering the E-axis (Fig. 6.1.1), in Poland some types of resources can be related to the UNFC Update 2019. From an economic standpoint, the most important in the UNFC Update 2019 are resources that fall into the E1 category (111, 112, 113 classes) – these are the economic resources that are to be sold. These resources correspond to the Polish extractable resources (in Polish "operatywne") in A+B, C_1 and C_2 categories. The only uncertainty applies to the 113 class (C_2 category) due to the limited accuracy of deposit data – an economic deposit assessment in this category generally is not expected in the international classification systems (also in the UNFC) because the data only enables an assessment of the resources as inferred (Nieć, Młynarczyk, 2014). However, the contribution of resources which fall in the C_2 category to total resources of exploited deposits in Poland is significant. As of the end of 2020, hard coal resources contributed 34.60% of anticipated economic resources and 17.80% of economic resources. In particular basins containing hard coal, it amounted to: 47.32% of anticipated economic resources within the exploited deposits of the USCB and 63.57% of the LCB (19.07% and 10.46% of economic resources, respectively). It suggests that resources in the C_2 category should be taken into account in this analysis. The UNFC Update 2019 does not distinguish a category that in the Polish system would correspond to economic resources in place (in Polish "przemysłowe"). The E2 category corresponds to resources whose extraction and sale is expected to become economically viable in the foreseeable future. That applies to exploitable resources for hydrocarbons, whereas for solid minerals it is not defined if resources are exploitable or in deposit – *in situ* (Nieć, 2010b). Thus:

- the 211, 212, 213 classes would indicate economic resources defined in a mineral deposit development plan;
- the 221, 222, 223 classes indicate anticipated economic resources (in Polish "bilansowe") which possibly can be exploited, but are not qualified as economic resources in place or as sub-economic resources (in Polish "nieprzemysłowe") of exploited deposits (they can be resources beyond a concession area or those located within non-available levels);
- the 231, 232, 233 classes correspond to anticipated economic resources in non-exploited deposits.

The E3 category covers anticipated sub-economic resources (in Polish "pozabilansowe") and sub-economic resources. It seems that lost resources (in Polish "tracone"; losses of economic resources) should also be in this category (Nieć, 2010b). It should be emphasized that resources treated as lost resources (losses) are not the subject of the UNFC and are not specifically distinguished by the UNFC.

The equivalents for field project status and technical feasibility (F-axis) in the Polish classification system are documents related to a particular deposit. There is no clear correlation of the F4 category – possible counterparts are regional reports on prospective raw material resources. In general, geological documentations can be assigned to the F3 category, mineral deposit development plans to the F2 category, and mining reports to the F1 category. Alternatively, when considering category definitions, geological documentation corresponds to the F2 category since a deposit has an issued exploitation concession, while mineral deposit development plans correspond to the F1 category since exploitation starts. Therefore, geological documentation can be assigned to both the F3 and F2 categories and the mineral deposit development plan to both the F2 and F1 categories.

A comparison between the system used in Poland and the UNFC Update 2019 is presented in Figure 6.2.1 and in Table 6.2.2.

Table 6.2.1. A comparison of geological knowledge of a deposit (the G-axis) between the UNFC Update 2019 and the Polish classification system (Nieć, 2010b, with authors' adjustments)

UNFC	Categories used in Poland (admissible estimate error)
G4	E (D_3), D_2, D_1 (officially not used)
G3	D (>40%), C_2 (up to 40%) for solid minerals; C (up to 50%) for hydrocarbons
G2	C_1 (up to 30%) for solid minerals; C (up to 50%) for hydrocarbons
G1	B (up to 20%) for solid minerals; B (up to 35%) for hydrocarbons A (up to 10%) for solid minerals; A (up to 20%) for hydrocarbons

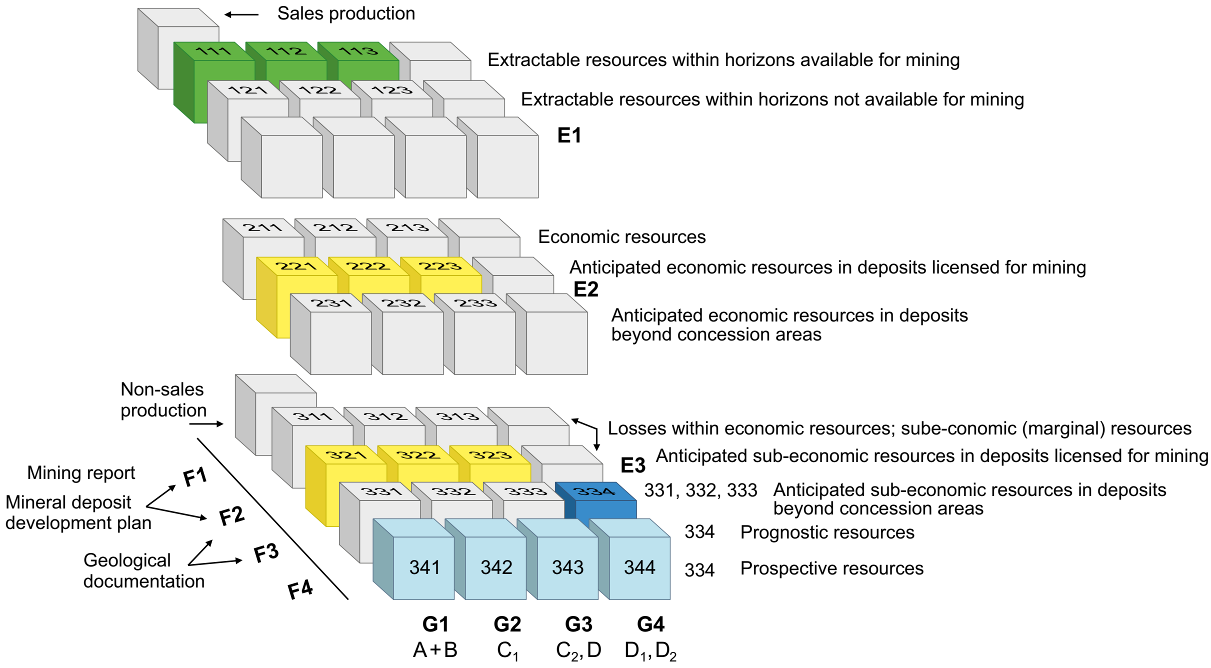


Figure 6.2.1. Correlations between the Polish and international (UNFC Update 2019) classification systems (Nieć, 2010a, with authors' adjustments)

Table 6.2.2. A comparison between the Polish classification system and UNFC Update 2019 (Nieć 2010a, with authors' adjustments)

Polish classification	UNFC Update 2019		
	Geological documentation		Deposit development plan
	Deposits licensed for mining	Deposits not licensed for mining (beyond concession areas)	
Resources prospective D_2 prognostic D_1		Resources 344 334	–
Anticipated economic resources D, C_2 C_1 A+B	Resources 223, 233 222, 232 221, 231		–
Anticipated sub-economic resources D, C_2 C_1 A+B	Resources 323, 333 322, 332 321, 331		–
Sub-economic resources D, C_2 C_1 A+B	–		Resources 313, 323 312, 322 311, 321
Economic resources D, C_2 C_1 A+B	–		Resources 213 212 211
Extractable resources D, C_2 C_1 A+B	–		Resources ("economic") 113, 123 112, 122 111, 121
Reserves C_2 C_1 A+B	–		–

The most substantial differences between the Polish system and the UNFC Update 2019 are (Nieć, 2010b, 2012):

- the mode of presentation of resources data: in Poland it is hierarchical, which means within the total amount of geological resources. Thus, geological resources are divided into anticipated economic and anticipated sub-economic resources. Anticipated economic resources are divided into economic resources in place and sub-economic resources and then economic resources in place are divided into extractable resources and losses. The UNFC Update 2019 – similarly to other international systems – is complementary, which means that it distinguishes extractable (exploitable) resources and other resources containing sub-economic resources, anticipated sub-economic resources and anticipated economic resources not qualified as economic and sub-economic resources;
- the important role of economic resources in place in the Polish system, which are not distinguished by the UNFC Update 2019;
- the division of resources that are not qualified for justified exploitation (in the Polish system);
- the lack of formal designation, in Poland, of exploitable resources (especially in the case of solid minerals deposits), which in Anglo-Saxon terminology are called "reserves".

Therefore, to attain full compatibility between the Polish system and the UNFC, data on Polish resources should be released separately (Nieć, 2010a):

- in the case of exploited deposits (deposits licensed for mining) – economic resources in place (21× according to the UNFC Update 2019), sub-economic resources (31×), anticipated economic resources not qualified as economic and sub-economic resources (22×), anticipated sub-economic resources (32×);
- in the case of non-exploited deposits (beyond concession areas) – anticipated economic resources (23×), anticipated sub-economic resources (33×). There should also be a distinction made for prognostic resources – class 234 and 334.

Therefore, economic resources in place can be presented as: 21× (economic resources) = 11× (extractable resources) + 31× (losses).

Table 6.2.6 [on page 40] presents the resources of selected raw materials using the Polish classification (as of the end of 2020) in comparison with the UNFC Update 2019. The number of raw materials is reduced only to those where exploitation is being carried out. Data originates from the publication "The balance of mineral resources deposits in Poland as of 31 XII 2020" (in Polish: "Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII 2020" – Szuflicki *et al.*, eds., 2021) and from the System of management and protection of mineral resources in Poland (MIDAS) maintained by the Economic Geology Department at PGI-NRI. To make data compatible with the UNFC Update 2019, resources were divided into resources of deposits licensed for mining and resources of deposits not-licensed for mining.

Due to the fact that resources data collected in "The balance..." do not contain information on extractable resources, relevant factors were assumed (as approximate values) for economic resources. In that manner, economic resources were reduced by losses. Factors for particular raw materials were:

- HNNG – 1.00; crude oil – 1.00; natural gas – 1.00; CBM – 1.00 (Nieć, Galos, 2015);
- copper and silver ores – 0.75; zinc and lead ores – 0.75 (Nieć, Galos, 2015);
- hard coal – 0.70 (Sobczyk, 2009; Kulczycki, Sowa, 2010); lignite – 0.90;
- rock salt – 0.35; sulfur – 0.50; diatomite rock – 0.75 (Nieć, Galos, 2015);
- bentonite, dolomite, gypsum and anhydrite, whiteware ceramic clays, stoneware ceramic clays, dimension and crushed stone, chalk, vein quartz, schist, magnesite, foundry sand, sand and gravel, quartz sand for cellular concrete and sand-lime brick production, filling sand, raw materials for earthworks, building ceramics raw materials, clay raw materials for cement production, clay raw materials for lightweight aggregate production, kaolin, feldspar raw materials, glass sand and sandstone, peat, limestone and marl – 0.75 (Nieć, Galos, 2015).

The methodology of comparing the Polish classification system with the UNFC Update 2019 – in the case of hard coal – is presented below Table 6.2.6. The same method was used for other raw materials.

Criteria from "The balance..." were applied to divide deposits into licensed for mining and beyond concession areas. Therefore, deposits licensed for mining include exploited deposits (symbol "E" used in "The balance..."), deposits exploited temporarily ("T"), mines in the course of a building process – for solid minerals; and mines prepared for exploitation or with trial exploitation – for hydrocarbons ("B"). However, keep in mind that economic resources are also being estimated for deposits which are not treated as exploited. These are deposits with a valid exploitation concession, but where production has not yet started. Aside from the concession, there is no knowledge of real deposit development (the start of work on a deposit). It applies to:

- deposits explored in C_2+D (for solid minerals) or C (for hydrocarbons) categories – these are deposits covered by preliminary exploration and marked as "P" in "The balance…",
- deposits explored in A+B+C_1 categories (for solid minerals) or A+B (for hydrocarbons) categories – these are deposits covered by detailed exploration and marked as "R" in "The balance…".

Therefore, some economic and sub-economic resources ("P" and "R" deposits) featured in "The balance…" will not be included in the UNFC Update 2019. It applies to the raw materials presented in Table 6.2.3 – as of the end of 2020. Most often, such resources constitute only a minor part of the total economic resources of a raw material, but for several raw materials their contribution may be significant (20–30%; in the case of amber as much as 74%). For potassium-magnesium salt (for which exploitation is not being carried out) the total economic resources volume is assigned to the "R" deposits.

Economic resources are also assessed for some deposits defined as abandoned in "The balance…" (marked as "Z"). These deposits have not been exploited for years, but the exploitation concession is still valid, so the economic resources formally still exist. It is assumed that such a deposit is treated as licensed for mining only formally, but there is no exploitation carried out. Therefore, deposits marked as "Z" are not included in the UNFC Update 2019. This also applies to the mineral raw materials presented in Table 6.2.4. For most of them such resources constitute only a minor part of the total economic resources, only a few of the mineral raw materials contribute significant resources – the highest being clay raw materials for lightweight aggregate production (about 60%), where there are 2 deposits with economic resources – 1 of them is exploited and 1 is abandoned. In the case of vein quartz the total volume of economic resources applies to 1 abandoned deposit – however the raw material has not been exploited for several years. Taking all this information into account, such resources should be omitted in the UNFC Update 2019.

Moreover, it is difficult to include resources of raw materials in the UNFC Update 2019 that are exploited on the basis of a concession issued by a county mayor. Such deposits do not require economic and sub-economic resources estimates – as according to Art. 26 point 3 of the GML there is no obligatory mineral deposit development plan elaboration required. Thus, anticipated economic resources of such deposits that are exploited be-

Table 6.2.3. Economic resources of "P" and "R" deposits (not included in the UNFC Update 2019; according to "The balance of mineral resources deposits in Poland as of 31 XII 2020" – in Polish; Szuflicki *et al.*, eds., 2021)

Raw material	Economic resources not included in the UNFC Update 2019	The percentage contribution to the total economic resources
Natural gas	21,931.72 Mm^3	29.83
Coal-bed methane	2,692.71 Mm^3	23.72
Crude oil	633.50 kt	5.26
Hard coal	347.01 Mt	7.21
Potassium-magnesium salt	3.46 Mt	100.00
Amber	59.74 t	74.19
Dimension and crushed stone	129.66 Mt	3.52
Glauconite-bearing sediments *glauconite*	0.34 Mm^3 *0.04 Mm^3*	34.00 *33.33*
Sand and gravel	670.48 Mt	15.59
Quartz sand for production of cellular concrete	2.59 Mt	10.53
Mineral raw materials for earthworks	0.85 Mm^3	13.36
Glass sand and sandstone	25.33 Mt	29.02
Peat	1.10 Mm^3	3.17
Limestone and marl for the cement industry	45.19 Mt	2.34
Limestone for the lime industry	4.53 Mt	0.38

Table 6.2.4. Economic resources of "Z" deposits (not included in the UNFC Update 2019; according to "The balance of mineral resources deposits in Poland as of 31 XII 2020" – in Polish; Szuflicki *et al.*, eds., 2021)

Raw material	Economic resources not included in the UNFC Update 2019	The percentage contribution to the total economic resources
Natural gas	756.75 Mm^3	1.03
Coal-bed methane	733.12 Mm^3	6.46
Crude oil	1.54 kt	0.01
Hard coal	74.11 Mt	1.54
Chalk	0.23 Mt	1.78
Vein quartz	1.35 Mt	100.00
Foundry sand	3.70 Mt	18.26
Sand and gravel	4.51 Mt	0.10
Quartz sand for production of cellular concrete	3.42 Mt	13.89
Quartz sand for production of sand-lime brick	0.38 Mt	0.98
Filling sand	19.60 Mt	23.89
Building ceramics raw materials	5.70 Mt	1.88
Clay raw materials for cement production	0.41 Mt	16.53
Clay raw materials for lightweight aggregate production	2.58 Mt	59.45
Feldspar raw materials	2.59 Mt	49.90
Glass sand and sandstone	0.83 Mt	0.95
Peat	1.35 Mt	3.89

come *de facto* extractable resources, plus losses. Deposits licensed for mining by a county mayor refer to such raw materials as i.e.: dimension and crushed stone (105 deposits), chalk (8), foundry sand (1), sand and gravel (1,989), quartz sand for production of sand-lime brick (4), building ceramics raw materials (68), peat (29) and limestone for lime industry (7). Table 6.2.5 shows the part of anticipated economic resources licensed for mining from which no economic resources were allocated – on the background of economic resources of deposits with concessions issued by a voivodeship marshal. Only for chalk, sand and gravel, and quartz sand for production of sand-lime brick, the deposit resources overseen by a county mayor are significant in magnitude – their contribution to deposit resources overseen by a marshal exceed 10%. In the case of other mentioned above raw materials, they constitute only minor parts.

The third issue in presenting national raw materials resources according to the UNFC Update 2019, is the legal possibility of estimating economic resources within anticipated sub-economic resources – according to a "Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans" (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511). Therefore, the anticipated sub-economic resources (which – by definition – do not meet the limiting parameter values that define a deposit) may sometimes be qualified for further stages of estimating resources to be exploited and – consequently – may be the subject to production. There are some exploited deposits with only the anticipated sub-economic resources, mainly natural gas and crude oil, but this is a very small number. Generally, the anticipated sub-economic resources of the exploited deposits for the particular raw materials constitute only a minor part of resources. In contrast, one UNFC Update 2019 assumption was qualifying anticipated sub-economic resources as resources not consider for future exploitation (Nieć, 2009). Economic and sub-economic resources of deposits licensed for mining, as estimated in mineral deposit development plans, have been allocated to anticipated economic resources – assessed in geological documentation/documentation supplements. However, with exploitation and better deposit exploration, particular resources types can be reclassified with the resulting sum of economic and sub-economic resources exceeding anticipated economic resources.

Considering natural gas and crude oil resources, data on anticipated economic and anticipated sub-economic resources collected by PGI-NRI and provided in "The bal-

Table 6.2.5. An analysis of deposit resources overseen by a county mayor of selected raw materials (according to "The balance of mineral resources deposits in Poland as of 31 XII 2020" – in Polish; Szuflicki *et al.*, eds., 2021, and the System of management and protection of mineral resources in Poland – MIDAS)

Raw material	Anticipated economic resources of deposits licensed for mining – with concession issued by a county mayor (deposits without a deposit development plan elaborated) [Mt]	Extractable resources calculated from deposit anticipated economic resources overseen by a county mayor (column 1×0.75) [Mt]	Economic resources of deposits licensed for mining – with concession issued by a marshal (deposits with a deposit development plan elaborated) [Mt]	Extractable resources calculated from deposit economic resources overseen by a marshal (excluding those overseen by a county mayor), (column 3×0.75) [Mt]	The percentage contribution of deposit extractable resources overseen by a county mayor, as part of the extractable resources overseen by a marshal [(column 2/ column 4)×100%]	Extractable resources enlarged by deposit resources overseen by a county mayor (column 2+4) (11× in UNFC) [Mt]
1	2	3	4	5	6	7
Dimension and crushed stone	53.27	39.95	3,549.45	2,662.09	1.50	2,702.04
Chalk	1.81	1.36	12.68	9.51	14.30	10.87
Foundry sand	0.12	0.09	16.56	12.42	0.72	12.51
Sand and gravel	391.08	293.31	3,626.75	2,720.06	10.78	3,013.37
Quartz sand for production of sand-lime brick	3.87	2.90	38.30	28.73	10.09	31.63
Building ceramics raw materials	11.60	8.70	297.90	223.43	3.89	232.13
Peat [Mm³]	0.82	0.62	32.26	24.20	2.56	24.82
Limestone for lime industry	3.59	2.69	1,184.16	888.12	0.30	890.81

ance…" refer to exploitable resources, whereas sub-economic resources are allocated to both exploitable and geological resources. Therefore, sub-economic resources can solely exceed the sum of anticipated economic and anticipated sub-economic resources. The remaining anticipated sub-economic resources (column "Anticipated sub-economic resources 32×" in Table 6.2.6) – obtained by subtracting sub-economic resources – would be negative, so by the UNFC Update 2019 they were assumed to be zero.

Assuming that the future issues of „The balance…" will cover the attempt to present domestic resources of raw materials according to the UNFC Update 2019 (in the form of aggregated table with particular raw material types – as presented in Table 6.2.6) and taking into account all restrictions mentioned above, it seems appropriate that:

- deposits licensed for mining contain deposits marked as "E", "T" and "B" in "The balance…";
- deposits marked as "P" and "R" with economic resources are treated as outside concession areas (not-licensed for mining) and their economic resources should be omitted by the UNFC Update 2019;
- abandoned deposits (marked as "Z") should be treated as deposits with completed exploitation and omitted in the UNFC Update 2019;
- total anticipated economic resources for deposits with no assessed economic resources (concessions issued by a county's mayor) should be treated as extractable resources and losses, as this prevents the direct comparison of data from "The balance…" to the UNFC Update 2019 classes (such operation is performed only for the needs of the UNFC Update 2019 – and the enlarged extractable resources volume, according to the Table 6.2.5 column No 7, is taken into account in the Table 6.2.6 – UNFC Update 2019 11×, 12× column);
- regarding natural gas and crude oil fields, anticipated sub-economic resources in the UNFC Update 2019 (32×) remaining after assignment of sub-economic resources should be assumed to be zero;
- resources of Polish raw materials should be presented according to the UNFC Update 2019 only for raw materials covered by mining ownership.

Table 6.2.7 presents a comparison of the two classification systems in terms of category definitions.

Table 6.2.6. The resources of selected mineral raw materials in Poland in comparison with UNFC Update 2019 – as of the end of 2020 (according to "The balance of mineral resources deposits in Poland as of 31 XII 2020" – in Polish; Szuflicki *et al.*, eds., 2021, and the System of management and protection of mineral resources in Poland – MIDAS). All explanations are given below the table

Raw material	Unit	National classification: Deposits licensed for mining (marked as "E", "T" and "B" in "The balance…"): Anticipated economic resources (in Polish "bilansowe"), including[1]: economic resources + sub-economic resources	Economic resources (in Polish "przemysłowe"): extractable resources + losses	Extractable resources (in Polish "opertywne")	Losses (in Polish "straty")	Sub-economic resources (in Polish "nieprzemysłowe")	Anticipated sub-economic resources (in Polish "pozabilansowe")	National classification: Deposits beyond concession areas ("P", "R"): Anticipated economic resources (in Polish "bilansowe")	Anticipated sub-economic resources (in Polish "pozabilansowe")	UNFC Update 2019: Deposits licensed for mining: Extractable resources 11× 12×	Economic resources 21×	Anticipated economic resources 22×	Sub-economic resources and losses 31× 32×	Anticipated sub-economic resources 32×	UNFC Update 2019: Deposits beyond concession areas: Anticipated economic resources 23×	Anticipated sub-economic resources 33×
High-nitrogen natural gas (HNNG)	[Mm³]	11,420.88	834.78	834.78	–	10,586.10	–	3,300	–	834.78	0.00	0.00	10,586.10	–	3,300	–
Natural gas[2]	[Mm³]	95,137.63	50,825.91	50,825.91	–	156,291.61	669.85	44,326.57	1,419.75	50,825.91	0.00	44,311.72[(3)]	156,291.61	–[3]	44,326.57	1,419.75
Crude oil[2]	[Mt]	20.44	11.40	11.40	–	155.91	0.01	1.16	0.33	11.40	0.00	9.04[(3)]	155.91	–[3]	1.16	0.33
Coal-bed methane (CBM)	[Mm³]	54,476.05	7,927.07	7,927.07	–	24,489.59	376.71	46,840.43	8,567.01	7,927.07	0.00	22,059.39	24,489.59	376.71	46,840.43	8,567.01
Copper and silver ores	[Mt]	1,590.98	1,117.17	837.88	279.29	360.04	1.04	1,411.19	811.05	837.88	0.00	113.77	639.33	1.04	1,411.19	811.05
Ag	*[kt]*	*84.32*	*67.16*	*50.37*	*16.79*	*13.98*	*0.04*	*24.42*	*41.10*	*50.37*	*0.00*	*3.18*	*30.77*	*0.04*	*24.42*	*41.10*
Cu	*[Mt]*	*28.99*	*22.31*	*16.73*	*5.58*	*5.05*	*0.01*	*20.70*	*13.18*	*16.73*	*0.00*	*1.63*	*10.63*	*0.01*	*20.70*	*13.18*
Zinc and lead ores	[Mt]	13.84	2.05	1.54	0.51	11.79	5.67	77.14	9.43	1.54	0.00	0.00	12.30	5.67	77.14	9.43
Pb		*0.20*	*0.04*	*0.03*	*0.01*	*0.16*	*0.12*	*1.23*	*0.15*	*0.03*	*0.00*	*0.00*	*0.17*	*0.12*	*1.23*	*0.15*
Zn		*0.53*	*0.08*	*0.06*	*0.02*	*0.45*	*0.21*	*3.32*	*0.41*	*0.06*	*0.00*	*0.00*	*0.47*	*0.21*	*3.32*	*0.41*
Hard coal	[Mt]	28,409.26	4,388.72	3,072.10	1,316.62	20,658.36	3,053.94	30,585.70	8,716.46	3,072.10	0.00	3,362.18	21,974.98	3,053.94	30,585.70	8,716.46
Lignite	[Mt]	1,110.62	937.69	843.92	93.77	152.71	39.41	22,063.55	3,447.62	843.92	0.00	20.22	246.48	39.41	22,063.55	3,447.62
Rock salt	[Mt]	14,923.05	1,740.42	609.15	1,131.27	10,824.66	–	96,739.10	10,214.18	609.15	0.00	2,357.97	11,955.93	–	96,739.10	10,214.18
Sulfur	[Mt]	19.29	14.47	7.24	7.23	4.82	0.68	256.69	14.64	7.24	0.00	0.00	12.05	0.68	256.69	14.64
Diatomite rock	[Mt]	0.64	0.20	0.15	0.05	0.44	–	–	–	0.15	0.00	0.00	0.49	–	–	–
Bentonite	[Mt]	0.49	0.34	0.26	0.08	–	–	2.33	0.25	0.26	0.00	0.15	0.08	–	2.33	0.25
Dolomite	[Mt]	202.05	125.47	94.10	31.37	–	6.53	260.21	0.55	94.10	0.00	76.58	31.37	6.53	260.21	0.55

Gypsum and anhydrite	[Mt]	80.90	65.25	48.94	16.31	11.44	–	128.23	19.13	48.94	0.00	4.21	27.75	–	128.23	19.13
Whiteware ceramic clays	[Mt]	3.73	0.73	0.55	0.18	–	–	56.25	–	0.55	0.00	3.00	0.18	–	56.25	–
Stoneware ceramic clays	[Mt]	7.10	3.27	2.45	0.82	0.10	5.10	57.52	8.40	2.45	0.00	3.73	0.92	5.10	57.52	8.40
Refractory clays	[Mt]	6.30	1.82	1.37	0.45	0.17	–	43.39	106.02	1.37	0.00	4.31	0.62	–	43.39	106.02
Dimension and crushed stone	[Mt]	6,213.74	3,549.45	2,662.09	887.36	513.86	96.98	4,372.82	387.33	2,702.04 (4)	0.00	2,097.16 (4)	1,414.54 (4)	96.98	4,372.82	387.33
Chalk	[Mt]	15.88	12.68	9.51	3.17	0.01	–	134.46	3.24	10.87 (4)	0.00	1.38 (4)	3.63 (4)	–	134.46	3.24
Phyllite schist	[Mt]	13.33	3.72	2.79	0.93	0.97	–	2.26	–	2.79	0.00	8.64	1.90	–	2.26	–
Quartzitic schist	[Mt]	8.67	2.74	2.06	0.68	1.02	–	–	–	2.06	0.00	4.91	1.70	–	–	–
Micaceous schist	[Mt]	6.64	3.03	2.27	0.76	3.61	–	–	–	2.27	0.00	0.00	4.37	–	–	–
Magnesite	[Mt]	3.47	3.47	2.60	0.87	–	–	5.92	2.18	2.60	0.00	0.00	0.87	–	5.92	2.18
Glauconite-bearing sediments	[Mm³]	1.78	0.67	0.50	0.17	0.37	–	7.25	–	0.50	0.00	0.74	0.54	–	7.25	–
glauconite		*0.21*	*0.08*	*0.06*	*0.02*	*0.04*		*1.09*		*0.06*	*0.00*	*0.09*	*0.06*		*1.09*	
Foundry sand	[Mt]	47.39	16.56	12.42	4.14	3.37	0.39	192.64	2.79	12.51 (4)	0.00	27.34 (4)	7.54 (4)	0.39	192.64	2.79
Sand and gravel	[Mt]	6,132.59	3,626.75	2,720.06	906.69	322.07	64.56	12,106.15	238.61	3,013.37 (4)	0.00	1,792.69	1,326.53 (4)	64.56	12,106.15	238.61
Quartz sand for production of cellular concrete (1.8) (5)	[Mt]	39.37	18.59	13.94	4.65	2.06	0.49	189.61	1.48	13.94	0.00	18.72	6.71	0.49	189.61	1.48
Quartz sand for production of sand-lime brick (1.8) (5)	[Mt]	85.77	38.30	28.73	9.57	11.10	–	320.17	4.95	31.63 (4)	0.00	32.50 (4)	21.64 (4)	–	320.17	4.95
Filling sand (1.7) (5)	[Mt]	720.83	62.46	46.85	15.61	39.23	67.01	2,997.41	319.45	46.85	0.00	619.14	54.84	67.01	2,997.41	319.45
Building ceramics raw materials (2.0) (5)	[Mt]	510.62	297.90	223.43	74.47	50.36	15.22	2,887.62	46.44	232.13 (4)	0.00	150.76 (4)	127.73 (4)	15.22	2,887.62	46.44
Clay raw materials for cement production	[Mt]	3.31	2.07	1.55	0.52	–	–	201.68	2.25	1.55	0.00	1.24	0.52	–	201.68	2.25
Clay raw materials for lightweight aggregate production (2.0) (5)	[Mt]	15.76	1.78	1.34	0.44	1.07	–	299.10	6.64	1.34	0.00	12.91	1.51	–	299.12	6.64
Kaolin	[Mt]	53.41	45.37	34.03	11.34	1.87	–	124.31	41.67	34.03	0.00	6.17	13.21	–	124.31	41.67

Table 6.2.6. Cont.

Raw material	Unit	National classification								UNFC Update 2019						
		Deposits licensed for mining (marked as "E", "T" and "B" in "The balance…")						Deposits beyond concession areas ("P", "R")		Deposits licensed for mining					Deposits beyond concession areas	
		Anticipated economic resources (in Polish "bilansowe"), including[1]: economic resources + sub-economic resources	Economic resources (in Polish "przemysłowe"): extractable resources + losses	Extractable resources (in Polish "opertywne")	Losses (in Polish "straty")	Sub-economic resources (in Polish "nieprzemysłowe")	Anticipated sub-economic resources (in Polish "pozabilansowe")	Anticipated economic resources (in Polish "bilansowe")	Anticipated sub-economic resources (in Polish "pozabilansowe")	Extractable resources 11× 12×	Economic resources 21×	Anticipated economic resources 22×	Sub-economic resources and losses 31× 32×	Anticipated sub-economic resources 32×	Anticipated economic resources 23×	Anticipated sub-economic resources 33×
Feldspar raw materials	[Mt]	5.82	2.60	1.95	0.65	1.14	–	122.88	13.18	1.95	0.00	2.08	1.79	–	122.88	13.18
Glass sand and sandstone	[Mt]	176.67	61.13	45.85	15.28	28.92	28.65	444.63	100.59	45.85	0.00	86.62	44.20	28.65	444.63	100.59
Peat	[Mm³]	43.86	32.26	24.20	8.06	3.41	3.66	39.12	0.97	24.82 (4)	0.00	7.37 (4)	11.67 (4)	3.66	39.12	0.97
Limestone and marl for cement industry	[Mt]	4,331.06	1,882.28	1,411.71	470.57	619.67	144.78	8,350.49	877.88	1,411.71	0.00	1,829.11	1,090.24	144.78	8,350.49	877.88
Limestone for lime industry	[Mt]	2,116.52	1,184.16	888.12	296.04	158.75	26.08	3,140.93	1,079.56	890.81 (4)	0.00	770.02 (4)	455.69 (4)	26.08	3,140.93	1,079.56

[1] For natural gas, crude oil and copper ores the part of economic resources was allocated within anticipated sub-economic resources, according to the "Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans" (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511).

[2] Natural gas and crude oil – anticipated economic and anticipated sub-economic resources within exploitable resources.

[3] There are no exploitable anticipated sub-economic resources given due to the fact that they were classified as sub-economic resources; sub-economic resources are estimated within geological resources (anticipated economic and anticipated sub-economic) and therefore contain also the total exploitable resources (anticipated economic and anticipated sub-economic).

[4] Including the county mayor's deposits (cmd); extractable resources include the cmd extractable resources (according to the Table 6.2.5 – column No 3), anticipated economic resources reduced by cmd anticipated economic (according to the Table 6.2.5 – column No 2), sub-economic resources and losses include the cmd losses (according to the Table 6.2.5 – column No 2 × 0.25 factor).

[5] Resources recalculated from Mm³ to Mt according to the density of specified minerals given in brackets.

<u>The recalculation of resources from Polish classification to UNFC Update 2019 – the case of hard coal:</u>

UNFC Update 2019 class **33×** = anticipated sub-economic resources in deposits beyond concession areas (in Polish: "pozabilansowe"; **8,716.46 Mt**).
UNFC Update 2019 class **23×** = anticipated economic resources in deposits beyond concession areas (in Polish: "bilansowe"; **30,585.70 Mt**).
UNFC Update 2019 class **32×** = anticipated sub-economic resources in deposits licensed for mining (in Polish: "pozabilansowe"; **3,053.94 Mt**).
UNFC Update 2019 class **31×**, **32×** = sum of sub-economic resources and losses in deposits licensed for mining (in Polish: "nieprzemysłowe" and "straty"; 20,658.36 + 1,316.62 = **21,974.98 Mt**).
UNFC Update 2019 class **22×** = anticipated economic resources in deposits licensed for mining minus minus sub-economic and economic resources (in Polish: "bilansowe" minus "nieprzemysłowe" and "przemysłowe"; 28,409.26 – 20,658.36 – 4,388.72 = **3,362.18 Mt**).
UNFC Update 2019 class **21×** = economic resources in deposits licensed for mining less the sum of extractable resources and losses (in Polish: "przemysłowe", less the sum of "operatywne" and "straty"; 4,388.72 – 3,072.10 – 1,316.62 = **0.00 Mt**).
UNFC Update 2019 class **11×**, **12×** = extractable resources in deposits licensed for mining (in Polish: "operatywne"; **3,072.10 Mt**).

Table 6.2.7. Definitions used by: the UNFC Update 2019 and the Polish national system – a comparison between the two classification systems

UNFC definitions – according to Annex I, which forms an integral part of the UNFC (UNECE, 2020), Polish national system definitions – according to: "Geological and Mining Law" dated the 9th of June, 2011 (Journal of Laws of 2021, Item 1420, unified text), "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987), "Regulation by the Minister of the Environment on a geological-investment documentation of a hydrocarbons field" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 968) and "Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans" (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511); prognostic and prospective resources – according to Nieć (2012). All explanations are given below each part of the table

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Resources**	**Definitions** [1]	**Possible classes**
E1	Development and operation are confirmed to be environmentally-socially-economically viable	Development and operation are environmentally-socially-economically viable on the basis of current conditions and realistic assumptions of future conditions. All necessary conditions have been met (including relevant permitting and contracts) or there are reasonable expectations that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to the user or market. Environmental-socio-economic viability is not affected by short-term adverse conditions provided that longer-term forecasts remain positive	111 112 113 114 121 122 123 124 131 132 133 134	Extractable resources	Part of economic resources in place which is obtained when reducing economic resources by technical losses (solid minerals)	111 112 113 (within horizons available for mining)
				Exploitable resources	Crude oil or natural gas resources, which are supposed to be extracted by applying current exploitation technology (hydrocarbons)	111 112 113 (within horizons available for mining) 121 122 123 (within horizons currently not available for mining)
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future	Development and operation are not yet confirmed to be environmentally-socially-economically viable but, on the basis of realistic assumptions of future conditions, there are reasonable prospects for environmental-socio-economic viability in the foreseeable future	211 212 213 214 221 222 223 224 231 232 233 234	Economic resources	Part of anticipated economic resources or anticipated sub-economic resources or – in case of brines, curative and thermal water – exploitable resources, within a designed mining area or detached part of a deposit designed for exploitation, which can be designed for mining according to detailed technical and economic analyses taking into account law requirements, including environmental protection	211 212 213
				Anticipated economic resources	Deposit resources (or part of a deposit) meeting the parameter limits that defines a deposit	221 222 223 (in deposits licensed for mining) 231 232 233 (in deposits beyond concession areas)

Table 6.2.7. Cont.

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Resources**	**Definitions**[1]	**Possible classes**
E3	Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early stage to determine environmental-socio-economic viability	On the basis of realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future; or, environmental-socio-economic viability cannot yet be determined due to insufficient information. Also included are estimates associated with projects that are forecast to be developed, but which will be unused or consumed in operations	311 312 313 314 321 322 323 324 331 332 333 334 341 342 343 344	Losses within economic resources	Part of economic resources predicted to be left in the deposit, which cannot be exploited in the foreseeable future (using economically and technically justified way) due to the exploitation method	311 312 313 (in deposits licensed for mining)
				Sub-economic (marginal) resources	Part of anticipated economic resources not-classified as economic resources within an area designed for exploitation, which can be designed for mining as a result of technical or economic or law change requirements, including environmental protection	321 322 323 (in deposits licensed for mining)
				Anticipated sub-economic resources	Deposit resources (or part of a deposit) not meeting the parameter limits that defines a deposit	331 332 333 (in deposits beyond concession areas)
				Prognostic resources	A confirmation of raw material occurrence which accumulation may form a deposit. Resources are being assessed on a basis of sparse, rare points of a raw material (deposit) occurrence (outcrops) and on interpretation of geophysical data which enables approximate delineation of a deposit area. An admissible error of deposit resources estimation may exceed 40%	334
				Prospective resources	An indication of probable deposit occurrence. A deposit is expected to occur on a basis of local indicators (geophysical, geochemical anomalies, isolated accumulations of raw material, outcrops, etc.). Possible resources estimated on a basis of general geological data by analogical methodology. An admissible error of deposit resources estimation is not defined	344

[1] The limit values of the parameters that defines the deposit – values of deposit parameters delineating the deposit geological boundaries.

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Documents**	**Definitions**	**Possible classes**
F1	Technical feasibility of a development project has been confirmed	Development or operation is currently taking place or, sufficiently detailed studies have been completed to demonstrate the technical feasibility of development and operation. A commitment to develop should have been or will be forthcoming from all parties associated with the project, including governments	111 112 113 114 211 212 213 214 311 312 313 314	Mining report/Deposit development plan (Prefeasibility study)	A document is understood as the current documentation of a state of development and exploitation of a deposit during its economic life, including current mining plans. An operator of a mine is generally responsible for preparing said plans. The study takes into consideration quantity and quality of minerals extracted during the reporting time, changes in economic viability categories due to changes in prices and costs, development of relevant technology, newly imposed environmental or other regulations, and data on exploration conducted concurrently with mining According to the GML, the mining report is a base for mining plant operation and specifies: 1) an organizational structure of a mining plant, in particular by indicating positions of management and operation supervision; 1a) mining plant boundaries; 2) specific activities to ensure: performing the activity covered by a concession; public safety; fire safety; safety of people residing in a mining plant, in particular concerning work health and safety; rational management of a mineral raw material deposit; environmental protection; protection of building objects; preventing of damage and their repair. The mining report shall be subject to conditions determined in a concession and a deposit development plan or a development plan for an underground carbon storage facility. In the case of geological work which is not subject of a concession – the report should account the conditions determined in a project of geological work. The mining report shall be prepared covering the period from 2 to 6 years or for the entire planned duration of the operations, if that is shorter	111 112 113 211 212 213 311 312 313 (classes according to the changes on E or G axis – still on F1)
F2	Technical feasibility of a development project is subject to further evaluation	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data acquisition and/or studies may be required to confirm the feasibility of development	121 122 123 124 221 222 223 224 321 322 323 324	Deposit development plan (Prefeasibility study)/ Geological documentation	A document provides a preliminary assessment of the economic viability of a deposit and forms the basis for justifying further investigations (detailed exploration and Feasibility study). It usually follows a successful exploration campaign, and summarizes all geological, engineering, environmental, legal and economic information accumulated to date on the project. Various terms are in use internationally for a Prefeasibility studies reflecting a current level of accuracy. The data required to achieve this level of accuracy are reserves/resources figures based on detailed and general exploration, technological tests at laboratory scale and cost estimations e.g. from catalogues or based on comparable mining operations [*continuation on the next page*]	121 122 123 221 222 223 321 322 323 (classes according to the changes on E or G axis – still on F2)

Table 6.2.7. Cont.

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Documents**	**Definitions**	**Possible classes**
F2 cont.					[*continuation*] According to the "Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans" (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511), the plan is elaborated within a mining area and shall specify: 1. requirements for rational management of a mineral raw material deposit, in particular through a comprehensive and rational use of the main raw material, as well as of accompanying raw materials, taking into account: a) geological conditions of a deposit occurrence; b) technological abilities and economic factors of exploitation; c) expected method of mining plant decommissioning, protection of resources remaining in a deposit after the end of exploitation, reclamation of an area after mining activities end; 2) environmental protection activities, including exploitation technology ensuring the reduction of the negative environmental impact. The deposit development plan specifies: 1) economic resources; 2) sub-economic resources; 3) losses within economic and sub-economic resources; 4) extractable resources for solid minerals	
F3	Technical feasibility of a development project cannot be evaluated due to limited data	Very preliminary studies of a project, indicate the need for further data acquisition or study in order to evaluate the potential feasibility of development	131 132 133 134 231 232 233 234 331 332 333 334	Geological study (Geological documentation)	A document is an initial evaluation of economic viability. This is obtained by applying meaningful cut-off values for grade, thickness, depth, and costs estimated from comparable mining operations. Economic viability categories, however, cannot in general be defined from the Geological study because of the lack of detail necessary for an economic viability evaluation. The estimated resource quantities may indicate that a deposit is of intrinsic economic interest, i.e. in a range of economic to potentially economic. The Geological study is generally carried out in the following 4 main stages: reconnaissance, prospecting, general exploration and detailed exploration. The purpose of the Geological study is to identify mineralization, to establish continuity, quantity, and quality of a mineral deposit, and thereby define an investment opportunity According to the GML, the document presents the results of geological work, along with its interpretation, definition of a degree of achievement of pursued aims as well as their justification. The geological documentation of a mineral deposit is prepared to determine its boundaries, geological resources, conditions of occurrence and to identify opportunities of exploitation of minerals from a deposit. The documentation shall define in particular: a type, quantity and quality of a raw material, including submission of information concerning accompanying raw materials and useful trace elements co-occurring and present in deposit substances harmful to the environment, as well as a category of exploration; location of a deposit, geological structure, form and boundaries;	231 232 233 331 332 333 (classes according to the changes on E or G axis – still on F3)

F3 cont.					elements of the environment surrounding a deposit; hydrogeological and other geological-mining conditions of a deposit occurrence; the state of land management within an area of documented deposit; parameter limits that define a deposit and its boundaries. Geological documentation comprises of the following types of documentation: 1. geological – of a mineral raw material deposit, excluding hydrocarbons; 1a. geological-investment – of a hydrocarbon field; 2. hydrogeological; 3. geological-engineering; 4. other than specified in previous points (e.g.: documentation of geological work not resulting in a documentation of resources – either of mineral raw material or underground water; documentation of a borehole aiming the exploration of a deep basement structure, not connected with a mineral raw material deposit documentation; decommissioning of a borehole). For the preparation of geological documentation for deposits of curative waters, thermal waters and brines, the requirements for hydrogeological documentation shall apply. If a geological documentation shall be the basis for granting a concession, exploration of a deposit occurs in details sufficient to enable the drafting of a deposit development plan. For preparing geological-investment documentation for hydrocarbon fields all of the mentioned above requirements should be met, but also the documentation should specify a way of hydrocarbons field development, exploitable resources, and an optimal variant of rational resources management (regarding the limitation of the environmental hazards)	
F4	No development project has been identified	Remaining quantities of product not developed by any project. These are quantities which, if produced, could be bought, sold or used (i.e. electricity, heat, etc., not wind, solar irradiation, etc.)	341 342 343 344		There is no corresponding document in Polish classification system – the closest one would be the regional case study with the assessment of perspective resources	344

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Resources category**	**Definitions**	**Possible classes**
G1	Product quantity associated with a project that can be estimated with a high level of confidence	Product quantity estimates may be categorized discretely as G1, G2 and/or G3 (along with the appropriate E and F Categories), based on the degree of confidence in the estimates (high, moderate and low confidence, respectively) based on direct evidence. Alternatively, product quantity estimates may be categorized as a range of uncertainty as reflected by either (i) three specific deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50 and P10)[1] are selected. [*continuation on the next page*]	111 121 131 211 221 231 311 321 331 341	For solid minerals: Measured resources – A and B	For solid minerals: A – mineral deposit is explored to an extent which allows current planning and carrying out exploitation with a maximum possible rate of resource absorption; delineation of structural and geological features, tectonics, resources on a basis of the opening-up, preparing and mining excavations, type, quality and technological properties of a mineral commodity on a basis of regular excavations sampling and data from the current production is required. The degree of the deposit exploration is sufficient enough to elaborate a mine management plan. The admissible error of average deposit parameters and deposit resources estimation in particular blocks cannot exceed 10% [*continuation on the next page*]	111 121 211 221 231 311 321 331 (classes according to the changes on E or F axis – still on G1)

Table 6.2.7. Cont.

UNFC Update 2019				Polish classification system		
Category	**Definition**	**Supporting Explanation**	**Possible classes**	**Resources category**	**Definitions**	**Possible classes**
G1 cont.		[*continuation*] In both methodologies (the "scenario" and "probabilistic" approaches), the estimates are then classified on the G Axis as G1, G1+G2 and G1+G2+G3 respectively. In all cases, the product quantity estimates are those associated with a project. Additional Comments: The G axis Categories are intended to reflect all significant uncertainties (e.g. source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimate forecast for the project. Uncertainties include variability, intermittency and the efficiency of the development and operation (where relevant). Typically, the various uncertainties will combine to provide a full range of outcomes. In such cases, categorization should reflect three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3		For hydrocarbons: Measured resources – A Indicated resources – B	[*continuation*] B – mineral deposit boundaries are delineated in details on a basis of the specially carried out exploratory excavations or geophysical measurements, delineation of structural and geological features, correlation of strata, main tectonics features has to be unambiguous, quality and technological properties of mineral commodity should be confirmed by sampling results in pilot-scale tests or commercial scale. The degree of deposit exploration is sufficient enough to elaborate a mine management plan. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 20% For hydrocarbons: A – data for category B are defined on a basis of exploitation results. The admissible error of average field parameters and resources estimate is up to 20% B – results of the implemented geological work are the basis to define a field's geological structure, field boundaries and reservoir parameters of oil bearing and gas bearing formations, as well as their variability in details; such data makes it possible to plan other work which is necessary to continue field exploration or its exploitation, when there is gas, oil or methane flow from at least one well producing an amount that has economic value. The admissible error of average field parameters and field resources estimation cannot exceed 35%	
G2	Product quantity associated with a project that can be estimated with a moderate level of confidence		112 122 132 212 222 232 312 322 332 342	For solid minerals: Indicated resources – C_1 For hydrocarbons: Inferred resources – C	C_1 – mineral deposit boundaries are evaluated on a basis of available data from exploratory excavations, natural outcrops or interpolation or extrapolation of geophysical measurements; a grade of deposit exploration makes it possible to prepare a Prefeasibility study of economic mining, including the detailed delineation of structural and geological features, tectonics and quality of a mineral commodity in a deposit, geological-mining conditions of exploitation, and allows an assessment of the influence of the intended exploitation on environment. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 30% C – hydrocarbons field boundaries are delineated on a basis of geophysical measurements and geological interpretation; such data makes it possible to plan other work which is necessary to continue field exploration or its exploitation, when there is gas, oil or methane flow from at least one well producing an amount that has economic value or, in the case of multi-horizontal fields, when hydrocarbons saturation of gas and oil horizons is known on a basis of the drilling	112 122 212 222 232 312 322 332 (classes according to the changes of E or F axis – still on G2)

G2 cont.					geophysics logging with gas, oil or methane flow from at least one well producing an amount of economic value. The admissible error of average field parameters and field resources estimation cannot exceed 50%	
G3	Product quantity associated with a project that can be estimated with a low level of confidence		113 123 133 213 223 233 313 323 333 343	For solid minerals: Inferred resources – C_2 and D For hydrocarbons: Inferred resources – C	C_2 – mineral deposit boundaries are evaluated on a basis of available data from isolated excavations, natural outcrops, interpolation or extrapolation of geophysical measurements; main structural and geological features and tectonics are identified; geological-mining conditions of exploitation are preliminary evaluated; quality of a mineral commodity is evaluated on a basis of regular sampling in the full range of commodity usage. The admissible error of average deposit parameters and deposit resources estimation cannot exceed 40% D – mineral deposit boundaries, geological features and anticipated resources are evaluated on a basis of available geological data, in particular from isolated excavations or natural outcrops, geological interpretation of geophysical measurements. The admissible error of average deposit parameters and deposit resources estimation may exceed 40% C – hydrocarbons field boundaries are delineated on a basis of geophysical measurements and geological interpretation; such data makes it possible to plan other work which is necessary to continue field exploration or its exploitation, when there is gas, oil or methane flow from at least one well producing an amount that has economic value or, in the case of multi-horizontal fields, when hydrocarbons saturation of gas and oil horizons is known on a basis of the drilling geophysics logging with gas, oil or methane flow from at least one well producing an amount of economic value. The admissible error of average field parameters and field resources estimation cannot exceed 50%	113 123 213 223 233 313 323 333 (classes according to the changes of E or F axis – still on G3)
G4	Product quantity associated with a Prospective project, estimated primarily on indirect evidence	A Prospective project is one where the existence of a developable product is based primarily on indirect evidence and has not yet been confirmed. Further data acquisition and evaluation would be required for confirmation. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty should be calculated for the Prospective project. In addition, it is recommended that the chance of success (probability) that the Prospective project will progress to a Viable project is assessed and documented	314 324 334 344	Prognostic resources – D1[2] Prospective resources – D2[2]	A confirmation of raw material occurrence which accumulation may form a deposit. Resources are being assessed on a basis of sparse, rare points of a raw material (deposit) occurrence (outcrops) and on interpretation of geophysical data which enables approximate delineation of a deposit area. An admissible error of deposit resources estimation may exceed 40% An indication of probable deposit occurrence. A deposit is expected to occur on a basis of local indicators (geophysical, geochemical anomalies, isolated accumulations of raw material, outcrops, etc.). Possible resources estimated on a basis of general geological data by analogical methodology. An admissible error of deposit resources estimation is not defined	334 344

[1] Where P90 means that there is a 90 per cent probability that the actual outcome will equal or exceed this estimate. Similarly, P50 and P10 reflect 50 per cent and 10 per cent probability respectively that the actual outcome will equal or exceed the estimate.

[2] Informal (not stated in law acts) allocations of resources categories – according to Nieć (2012).

7. Geological information

M. Sokołowski

7.1. Geological information – definition and sources

Carrying out an activity in the area of prospecting, exploration and exploiting raw materials from deposits is strictly connected with the definition of "geological information". In Polish law acts, coming from the GML and regulations issued on its basis, there were several important definitions connected with the geological information meaning in various aspects of its use. In the broadest sense, geological information are geological data and samples together with the results of their processing, including their interpretation, particularly presented in geological documentations and saved on a data storage device. Processed geological information includes the following data:

- boreholes profiles (lithological, stratigraphic);
- geological cross-sections;
- maps and other cartographic elaborations;
- descriptions in the text parts of geological documentations;
- statistical elaborations (resources estimates, parameter averages, etc.);
- and other heading data (metadata) identifying objects (boreholes, places of performed geophysical studies, deposits), especially related to spatial location, administrative location, function, type, etc.

Geological information can also be data that is the result of direct observations and measurements gained from carrying out geological work – including the results of chemical-physical indications of solid, liquid and gas geological samples, as well as all results gained from surface and borehole logging geophysics measurements together with accompanying information allowing further processing and interpretations.

A specific information type is so-called "geological information from current documentation" understood as the geological data and samples together with the results of their measurements, obtained by entrepreneurs – as the result of currently conducted geological work. Entrepreneurs performing: geological work aimed at prospecting and exploration for raw material deposits under state ownership, storage of carbon dioxide in the subsurface, drilling deep basement boreholes, regional exploration of geological structure, assessments of hydrogeological and geological-engineering conditions for non-reservoir substances storage, and storage of waste or carbon dioxide in the subsurface – have to forward the information in the time specified by the GML – within 14 days from the date of acquiring data and results from samples, and within 60 days when only geological samples are available.

Regardless of the type of activity, the final results of any geological work along with their interpretation, should be presented in the form of relevant geological documentation describing the conducted work, that is – geological documentation of raw material deposit, hydrogeological documentation, geological-engineering documentation and what is referred to as "other geological documentation". The first three types of above-mentioned documentations have to be approved by a relevant geological administration body, whereas the fourth type has to be only forwarded to the appropriate geological administration body. The geological administration bodies together with the PSG collect, record, retain, protect and provide geological information in forwarded documents, samples and other geological data storage media.

7.2. Property rights to geological information, right to use geological information

Under the current Polish law, there are two types of rights distinguished that pertain to geological information, which are the property rights to geological information and the right to the use geological information. "Property rights to geological information" is a definition similar to ownership, however due to an immaterial character of information, regulations speak of not "an owner" but "entity having right to geological information". According to the Art. 99, par. 1 of the GML, the property rights to all information obtained during geological work shall be awarded to the State Treasury. The "right to use geological information" is a right that can be obtained based on the Polish law or on the basis of a relevant agreement/contract. According to the Art. 99, par. 2 of the GML, the entity which bears the costs of legally conducted geological work and obtained the geological information, has a right to use the information free of charge throughout perpetuity and within all exploitation areas. Moreover, the GML guarantees that for a period of 3 years from the date of delivery of geological documentation approval decision, or from the date of forwarding "other documentation" to a relevant geological administration body, the entity which obtained the right to use the geological information will be granted exclusivity to that information – in order to obtain the approval for: exploring raw materials from deposits, storage of substances in the subsurface, storage of waste in the subsurface, storage of carbon dioxide in the subsurface and activity requiring approval under the water law. If within the exclusivity time period the entity obtains a concession or another relevant decision, the right to exclusivity will be extended for the period that concession or decision was issued, and additionally for two more years after the concession or decision expires. It should be emphasized that the latter rule (+2 years) does not apply to the activity related to hydrocarbons exploitation.

7.3. Access to geological information

According to the GML, access to the geological information is regulated by the geological administration bodies and the PSG. These entities collect, record, archive and protect said geological information.

Access to geological information is being implemented in a dual manner. The first is open access, implemented by providing an access to archival materials containing geological information. Access can be granted by providing paper documents available in geological libraries or by providing web services enabling access to said information in digital form. Access is free of charge and does not require any submission of application, there is only issuing of documents for particular person recorded. During access to any reprint, copy, printout, digital version or other documents and data sets, recording is permitted. In the case of the geological samples, photography is permitted to, however no physical sampling can take place without obtaining proper permission.

The second is access to information granted via application which, due to rights to use geological information, may require providing additional documents confirming that they are possible to access. The State Treasury owns the property rights to most geological information. In principle, the use of the geological information owned by the State Treasury is free of charge, with the applicant bearing only material costs (copying, recording on paper or on electronic device). There are exceptions when the information is to be used to exploit raw materials deposits, store substances in the subsurface, store waste in the subsurface, store carbon dioxide in the subsurface, and any activity requiring approval in terms of the water law. Additionally, access to some geological information is provided for a fee, in cases when geological data refers to: raw materials covered by state ownership, such as core samples from boreholes conducted for the deep exploration of the basement or for regional research on the geological structure of the country, as well as when such data constitute the results of geophysical measurements. Using information from the above-mentioned areas is subject to a fee determined on the basis of a valuation supplied by the entity applying for the access. When the valuation verification is made, the State Treasury provides a contract for the time-limited use of indicated geological information. In most cases, the State Treasury is represented by the Minister of Climate and Environment – the Minister represents the country in all areas excluding only the use of information in order to obtain permits pertaining to the water law. Details referring to the valuation of information and on the procedure for contracts are described in the "Regulation by the Minister of the Environment on the paid use of geological information" (dated the 20th of December, 2011 – Journal of Laws of 2011, Item 1724).

In a case when the property rights to the geological information specified in the application are owned by another entity than the State Treasury, the application should contain written permission of such an entity.

Particular protection is related to information from current documentation of the conducted geological work. According to Art. 82, par. 8 of the GML, geological information from ongoing documentation of geological work and its results cannot be the subject of open access or access until the approving decision of geological documentation is delivered or until the date of forwarding of geological documentation prepared for the use of underground heat and conducting geophysical measurements for exploration of geological structures related to hydrocarbons.

7.4. Scope of geological information

Collecting, recording, archiving, protecting and providing access to geological information in Poland is conducted by the county and voivodeship geological administration entities and by the PSG, which is the entity supporting the Minister of the Climate and Environment. According to the GML, the PGI-NRI fulfills the role of the PSG. For more than 100 years, PGI-NRI has been conducting various activities on the subject of geology. Beside the tasks strictly connected to the implementation of geological work, a very important part of PGI-NRI activity are projects within the area of collecting, processing and providing geological information. The implementation of these projects is carried out directly on the basis of the GML.

One of these tasks is the maintenance of the Central Geological Archive (CGA), as a separate asset, collecting and providing access to said collections, as described in the GML and the regulations. The organizational entity for this task is PGI-NRI, and it has been tasked with carrying out the tasks of the CGA by means of the National Geological Archive (NGA). The NGA is the main national archive for geological-environmental documentations and geological samples, where besides from the "official" asset (CGA), there have been significant geological information resources collected, coming from PGI-NRI's own resources, which originated from tasks carried out for other entities or were gained from other archives.

As of the end of 2020, the NGA contains more than 656 thousands of geological documents recorded (including 415 thousand documentations and 241 thousand maps) and more than 900 thousand linear meters of geological samples (cores, clastic samples and other). Materials collected in the NGA is used to support geological researches, spatial planning and environmental management, help with rational raw materials management and water management, but their main use is the implementation of tasks conducted by the PSG and the PSH (Polish Hydrological Survey, in Polish: państwowa służba hydrogeologiczna). To facilitate the access to geological information, its better use and processing, and for the purpose of protecting all the collected data, the NGA conducts an ongoing digitization process of the collected documents. As of the end of 2020, there were about 80 thousand pieces of geological documentations scanned, which when placed next to each other, occupy nearly 2 km of shelving in NGA storage.

7.5. Digital databases

The main source of data collected by the NGA is documentation forwarded by the geological administration bodies and entities conducting geological work, as well as the results from researches conducting work for PGI-NRI. For several years, the legal obligation to forward data and geological documentation, including in digital format, has been applied. The collected archival materials are the subject of digital recording and processing, so that their further use is possible through web services and electronic means of communication. PIG-NRI ensures access to the special Internet services presenting spatial data, descriptive data, thereby enabling the graphical presentation of data. The sets of PGI-NRI information resources contain geological and hydrogeological data. The most widely available set of geological information is the digital Central Geological Database (CBDG; in Polish: Centralna Baza Danych Geologicznych), available at http://baza.pgi.gov.pl. It is the largest Polish digital geological data collection available in the metadata and full digital data formats. This database allows access to the spatial data, and moreover contains the graphical and descriptive information on boreholes, archival geological documentation, as well as geophysical research of various types. Most of the data is made available free of charge by means of specialized applications on the CBDG website, including spatial data – using the geographical browser, also available for mobile devices. The most important sub-systems of the CBDG are:

- **Graphical browser** – enabling access to spatial data in the form of map services covering all of the serial geological maps (e.g. the detailed geological map of Poland in the 1:50,000 scale);
- **Archival documents** – enable access to data on archival geological elaborations sets, maps published in paper version, and aerial photos. It also allows the possible recording of document rentals;
- **Boreholes** – containing detailed information on stratigraphic profiles, lithological profiles, geophysical researches and cores. The profile browser, which

is a component of the application, presents selected data obtained from the borehole in graphical form;
- **Geophysics** – containing information on geophysical documentations, results of drilling geophysics research, seismic, and other aerial geophysical measurements;
- **Landslide Counteracting System** (SOPO; in Polish: System Osłony Przeciwosuwiskowej) – its main aim is to explore and document all landslides and areas potentially at risk of mass movements in Poland and to establish the system of deep and aerial monitoring of 60 selected landslides;
- **Geological-Engineering Database** (BDGI, in Polish: Baza Danych Geologiczno-Inżynierskich) – the largest digital data set regarding construction conditions on selected areas of Poland.

Detailed available data on raw materials are contained in domain-specific systems, such as MIDAS, Mineral Resources of Poland or InfoGeoSkarb. Hydrogeological data is collected separately, in thematic databases available on the PSH websites (www.psh.gov.pl and http://spd.pgi.gov.pl/PSHv8).

CHAPTER II

Mineral resources

8. Energy raw materials

8.1. Lignite

M. Tymiński, S. Mazurek

Lignite as a part of brown coals is defined as lower grades (low rank) of coal (intermediate in the qualification between hard coal and peat), with a calorific value below 24 MJ/kg. It is divided into subbituminous coal (with a calorific value above 17.5 MJ/kg – hard form) and lignite (below 17.5 MJ/kg – soft form). In Poland, lignite deposits occur in the central and western parts of the country (Plate 2), in younger geological formations, mainly those (according to the former classification) Tertiary of age. Older brown coal deposits are known to occur also in Jurassic, Carboniferous and rarely – in Cretaceous and Triassic sediments.

Lignite deposits originated both, in sediments of platform areas and in orogenic belt sedimentary basins. They form extensive seams, ranging from a few meters to several dozen meters in thickness. They also occur in the form of lenses. The overburden thickness is usually quite small, which makes opencast mining possible. Seams of older brown coal are often situated too deep below the surface for opencast mining, requiring underground mining. This is also the case for coal seams occurring in glacitectonic folds. Underground mining methods have lately been used in Poland to mine coal from the Babina and Sieniawa deposits.

Lignite resources are documented assuming the following parameter limits, which establish the deposit and its boundaries, for opencast mining: a maximum bottom depth of the deposit – 350 m, a minimum thickness of lignite in the seam – 3 m and a maximum ratio of the total thickness of the overburden and intercalation to the thickness of the deposit of 12:1. In addition, a minimum weighted-average net calorific value in a coal seam (with intercalations) should be greater than 6.5 MJ/kg (with a lignite moisture content of 50%). These are the limits for geological-mining parameters and qualitative parameters for thermal coal which is common in Polish lignite deposits – typical ortholignite. For the purposes of underground gasification or production of liquid fuels in the ground installations (mentioned in the "Polityka energetyczna Polski do 2040 r." – MKiŚ, 2021), the parameter limits that define a deposit and its boundaries (in Poland referred to as the "balancing criteria") have not been established.

A possible further extension of the lignite resource base, in terms of traditional opencast mining, is particularly related to the formalization (category D in geological documentation) of the already known lignite occurrences for which documentation has not been provided, due to their low degree of geological exploration. According to current data, Polish prognostic brown coal resources with balance sheet potential amount to 18,251.79 Mt (Kasiński *et al.*, 2020).

Poland's anticipated economic resources of lignite amounted to 23,201.64 Mt as of the end of 2020 (Tab. 8.1.1). The majority of resources – that is 23,201.00 Mt – constitute thermal coal, with the remaining 0.64 Mt being bituminous coal (documented in the C_2 category in the Kaławsk-szyb główny deposit). There was also coal usable for briquette production and coal suitable for a production of coal tar and coal liquefaction into fuel, which has been documented in the past. Currently, all these types of coal are used and treated as thermal coal only. The anticipated economic resources within exploited deposits in 2020 amounted to 1,110.62 Mt and accounted for 4.79% of total anticipated economic resources. In 2020, lignite was being exploited in 5 mines in Poland: Bełchatów, Turów, Adamów, Konin and Sieniawa. In the February of 2021, the exploitation of the Adamów deposit has ended.

More than 22% (5,185.33 Mt) of the anticipated economic resources constitute the resources of deposits within the Poznań Through. These are Czempin, Gostyń, Krzywin and Mosina deposits, where potentially strip mining is currently precluded on environmental grounds and in a connection with large scale of production farms. These are the main conflicts of interest to be resolved between local communities, ecological organizations and supporters of developing the deposit, before any exploitation starts. Therefore, it might seriously complicate the development of deposits in the future. On the 2nd of February, 2021, the Council of Ministers approved "Polityka energetyczna Polski do 2040 r." (MKiŚ, 2021) – in the document, the development of minable lignite deposits for the purpose of energy is generally not expected. An exception is a possible opening of the following deposits for exploitation:

Table 8.1.1. Lignite resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**91**	**23,201.64**	**2,240.89**	**3,510.09**	**12,645.52**	**4,805.14**	**3,517.27**	**937.69**
Including resources of exploited deposits								
TOTAL	9	1,110.62	983.13	117.10	10.39	–	39.41	937.69
1. Deposits of operating mines	8	1,109.47	983.13	115.98	10.36	–	39.41	936.86
2. Deposits exploited temporarily	1	1.15	–	1.12	0.03	–	–	0.83
Including resources of non-exploited deposits								
TOTAL	73	22,063.55	1,241.00	3,386.80	12,630.62	4,805.14	3,447.62	–
1. Deposits covered by detailed exploration	34	5,821.03	1,241.00	3,386.80	1,193.23	–	872.64	–
2. Deposits covered by preliminary exploration	39	16,242.52	–	–	11,437.39	4,805.14	2,574.98	–
Including abandoned deposits								
Abandoned deposits	9	27.47	16.77	6.20	4.51	–	30.23	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

- Złoczew – without an environmental decision since 23rd of September, 2021 – (Generalny Dyrektor Ochrony Środowiska, 2021 – https://www.gov.pl/attachment/f105bae3-affc-4c65-a830-0f178ca345dd – in Polish);
- Ościsłowo – the ZE PAK SA made a decision not to apply for developing the deposit (https://ri.zepak.com.pl/pl/aktualnosci/1469-zielone-kierunki-strategii-ze-pak-sa-zaakceptowane-koniec-z-energia-z-wegla-najpozniej-w-2030-roku.html – in Polish);
- Gubin – as a reserve deposit – "Polityka energetyczna Polski do 2040 r." (MKiŚ, 2021, page 16; in Polish) states that: "Research and development activities should be aimed at searching for innovations to reduce the environmental burden resulting from coal mining and new solutions that contribute to low-emission, efficient and flexible use of the raw material (e.g. gasification, liquid fuels)". The Gubin deposit was indicated as a main lignite deposit resource for energy production and future gasification (Kasiński *et al.*, 2006).

Economic resources of lignite amounted to 937.69 Mt as of the end of 2020 and decreased by 56.86 Mt (5.72%) in comparison to 2019. The change in economic resources was caused by production, as well as losses during said production, and better deposit exploration during ongoing exploitation and from the elaborated supplements to deposit development plans.

The lignite output, according to data provided by the concession holders, decreased in 2020 by 5.56 Mt (10.51%) in comparison to the previous year and amounted to 47.30 Mt. The exploitation was carried out from 8 deposits, and there was no output recorded for the Sieniawa 1 deposit. The majority of the domestic output came from outcrops exploited by the PGE GiEK S.A., especially from the Bełchatów-pole Szczerców deposit (33.66 Mt), which accounted for 71.16% of domestic production (in 2018 and 2019, the percentage contributions were much lower – 56.66% and 68.89%, respectively). The gradually increasing output from the Szczerców field compensates the nearly-depleted Bełchatów field allowing a stable level of the exploitation to supply the Bełchatów power station. The output from the Bełchatów-pole Bełchatów deposit amounted to 2.54 Mt (5.37% of domestic output in 2020, with percentage contributions in 2018 and 2019, 19.92% and 8.28%, respectively). Output from the Turów deposit was equal to 5.07 Mt (10.71% of the domestic output). The exploitation levels in deposits located in the Konin area (to the needs of ZE PAK SA) amounted to: Tomisławice deposit –

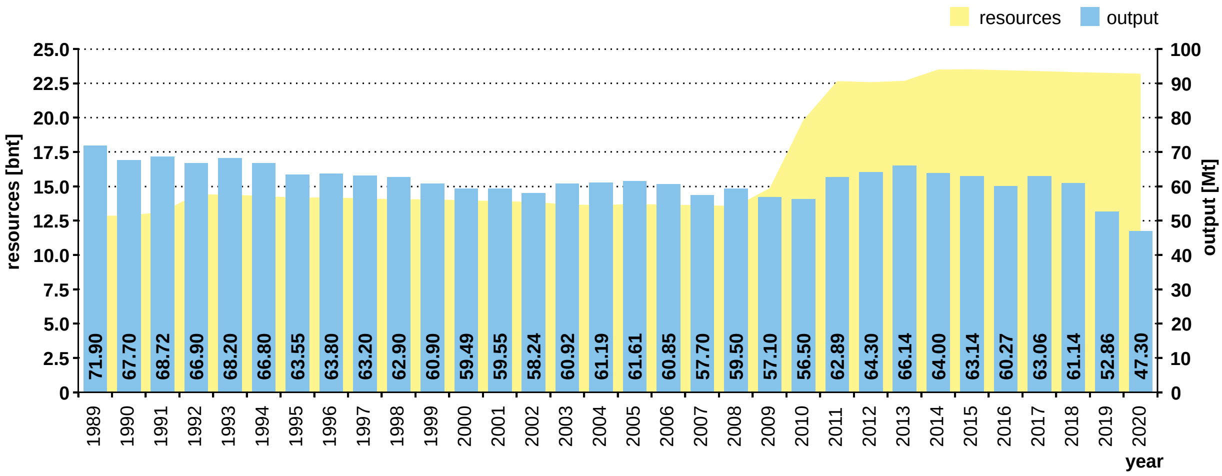


Figure 8.1.1. Lignite anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

2.11 Mt (4.46% of the domestic output); Pątnów IV – 1.59 Mt (3.35%), Drzewce – 1.41 Mt (2.99%) and Adamów – 0.72 Mt (1.51%). The remaining output came from the Sieniawa 2 deposit and was 0.21 Mt (0.45% of the domestic output). In 2021, the exploitation from the Adamów deposit ended.

Figure 8.1.1 shows changes in anticipated economic resources and the output of lignite in Poland in the years 1989–2020. The resources increased in 1992 due to better exploration of the Turów deposit and the documentation of 3 new deposits – Torzym, Rzepin and Dęby Szlacheckie. Over the next 16 years resources did not change significantly, with significant increase only in 2009–2011. It was the result of documenting 16 new deposits with total resources amounting to 7,236.61 Mt: Gubin 1, Gubin-Zasieki-Brody, Lubsko, Łęki Szlacheckie, Mosina, Nakło, Naramowice, Oczkowice, Radomierzyce, Radziejów, Ruja, Sieniawa 2, Szamotuły, Węglewice, Więcbork and Władysławów II. The next 4 years were characterized by a growth in resources (by 932.36 Mt) and varying production. In 2014, another increase was the result of approving new documentation with recalculated resources for the Oczkowice deposit (853.25 Mt). In 2015, there was 1 new deposit documented – Gubin 2 with resources equal to 1,033.8 Mt. At the same time new documentation elaborated and accepted for 3 other deposits: Gubin, Gubin 1 and Izbica Kujawska caused a decrease in resources of 1,018.92 Mt. In the following 5 years, resource reductions were caused by exploitation and exploitation-related losses, and amounted to: 65.06 Mt in 2016, 66.07 Mt in 2017, 69.54 Mt in 2018, 53.69 Mt in 2019, and 60.19 Mt in 2020. The total resources decline in 2016–2020 was equal 314.55 Mt.

Lignite output was generally decreasing in 1990–2010 with a slight growth between 2003 and 2006. Much bigger output was produced in the 2011–2013 period (mainly from the Bełchatów-pole Szczerców, Pątnów IV, Władysławów, Koźmin, and Tomisławice deposits) and reached as high as 66 Mt. Then, the total domestic exploitation decreased significantly in 2014 and 2015 – by 2.14 Mt and 0.86 Mt, respectively. It resulted from output drops recorded for the Turów, Adamów and Drzewce deposits. A brief period (2016–2018) brought about output fluctuations, whereas in 2019–2020 the exploitation volume fell to the lowest level of the entire presented period – by 47.30 Mt. In 2019 an output decrease was mainly the result of declining exploitation from the Bełchatów-pole Bełchatów deposit (by 7.81 Mt), whereas in 2020 the output decreased due to the cutting of exploitation from the Bełchatów-pole Szczerców and Bełchatów-pole Bełchatów deposits – by 2.75 Mt and 1.84 Mt, respectively.

8.2. Coal-bed methane (CBM)

A. Malon, M. Młynarczyk, M. Tymiński

Coal-bed methane is a natural gas trapped in coal and occurring in the form of gas particles adsorbed at coal grains. A drop in bed pressure along with mining activities is followed by an increase in a CBM desorption and it is released from coal and surrounding rocks to active exploitation areas in a coal mine. The release of methane is a serious safety concern as it can create an explosive hazard. Therefore, much attention is paid to draining methane from coal beds before and in the course of coal mining. This is achieved by methane capture on advance of longwall coalfaces by boreholes drilled into the front of the face and a reduction of concentration of methane to an acceptable level by ventilating work areas.

Recent years witnessed the development of a technology for draining methane from coal beds by multiple boreholes drilled from the surface. Such technology involves hydro fracturing of coal beds and surrounding rocks and filling up fissures with a permeable medium (usually sand) to facilitate migration of CBM released by desorption. The next step is the removal of water from coal beds to achieve a drop in bed pressure in the area of a given borehole, which is necessary to start of CBM desorption, emission and migration processes. Recovery of CBM by means of production wells is treated as natural gas production from an unconventional source.

CBM recovery is determined on one hand by safety issues and on the other hand is treated as collecting the gas from unconventional sources – due to its form of occurring which demands the application of special recovery desorptive technologies.

CBM deposits have only been documented in the USCB coal deposits. CBM concentrations in the LSCB and the LCB coal deposits are much smaller than in the USCB. Their economic importance is still to be established.

Prospecting made it possible to evaluate the CBM resources and show their presence in 65 hard coal deposits, in the area of the USCB. In 2020, these anticipated economic resources amounted to 107,229.25 Mm^3. The majority of the anticipated economic resources consist of resources documented in the C category (98,561.34 Mm^3 – 91.92%). Resources documented in the A and B categories amount only to 8,667.91 Mm^3 and account for only 8.08% of domestic anticipated economic resources. Anticipated sub-economic resources have been documented within 8 deposits and are equal to 9,411.45 Mm^3, of which 9,316.35 Mm^3 are resources in the C category (98.99% of the total anticipated sub-economic resources) and only 95.10 Mm^3 are resources in the A and B categories (1.01%). In 2020, economic resources of CBM, located within 33 deposits, were equal to 11,352.90 Mm^3. These resources increased by 921.42 Mm^3 (8.83%) in comparison with the previous year.

In the latest edition of "The balance of prospective mineral resources of Poland" (in Polish: "Bilans perspektywicznych zasobów kopalin Polski" – Szamałek *et al.*, eds., 2020), there was an updated assessment of exploitable anticipated economic resources of CBM in Poland (Hadro, Jureczka, 2020). The assessment was prepared on a basis of current obligatory criteria for determining CBM deposits from hard coal beds – both as a main raw material and as an accompanying raw material. There were 2 types of resources distinguished. First – prognostic resources of CBM as an accompanying raw material. These included the resources documented in hard coal deposits in the D category, which are not reported in the resources register. Second type was prospective resources of CBM as a main raw material. These included all remaining resources which have not been documented so far, without determining prognostic resources due to a relatively high uncertainty of the resources quantity assessment. Both types of resources were calculated assuming the following parameters: a minimum coal beds thickness of 0.6 m; CBM content is ≥4.5 m^3/t of pure carbon substance within the limits of a deposit area; up to a depth of documenting the coal deposit in the case of an accompanying raw material or up to a depth of 1,500 m in the case of a main raw material. The prospective resources of CBM as the main raw material were assessed below the deposits in which CBM is the accompanying raw material, in the deposits where CBM had not been documented as the accompanying raw material or within the areas which had not been documented. The total prognostic resources of CBM in Poland as of the end of 2018 amounted to 1.69 bnm^3 (only within the USCB area), whereas the prospective resources amounted to 111.27 bnm^3 – including 1.75 bnm^3 within the LSCB area, 94.33 bnm^3 within the USCB area and 15.19 bnm^3 within the LCB area.

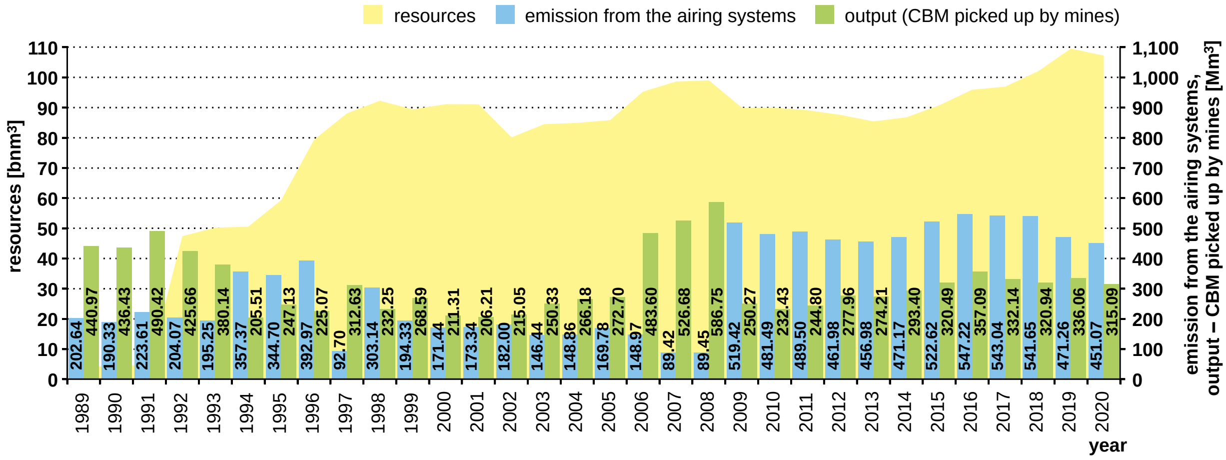


Figure 8.2.1. Coal-bed methane exploitable resources, emission from the airing system and output (CBM picked up by mines) in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

In the 1989–2020, the resources (exploitable anticipated economic) of CBM increased from 4.24 to 107.23 bnm³ (Fig. 8.2.1). The most significant increase was recorded in the 1991–1998 period – from 4.95 to 92.29 bnm³. The following 10 years were characterized by fluctuations in resources, however an increasing tendency was quite visible and resources grew to the amount of 99.04 bnm³. Within the next 5 years (2009–2013) they declined by 13.61 bnm³ (13.74%). Then, in 2014–2015, resources increased significantly (by 5.34 bnm³) which resulted, among others, from: documentation of new deposits: Barbara-Chorzów 2, Brzezinka 3 and Bzie Dębina 2 – all of them with CBM as an accompanying raw material; Studzienice 1 and Żory-Suszec 1 – documented beyond areas of hard coal exploitation; Jankowice-Wschód and Mszana – with CBM as a main raw material; recalculations of resources accepted for the Knurów, Borynia; Brzeszcze and Halemba II deposits; the updating of resources estimated for the Jankowice deposit. The last 5 years (2016–2020) were characterized by the significant growth of resources – from 90.77 bnm³ in 2015, to 107.23 bnm³ in 2020 (the highest amount in the whole presented period). The increase in 2016 (by 5.18 bnm³) was a result of documentation of 4 new deposits – 1 within the areas of hard coal exploitation (Chwałowice 1), 2 beyond such areas (Anna and Marcel 1) and 1 with CBM as a main raw material from an abandoned coal mine (Wilchwy); and a result of new documentation with recalculated resources for the Rydułtowy and Szczygłowice deposits. Another significant growth of resources took place in 2018 (by 5.07 bnm³) and resulted mainly from the documentation of 3 new deposits (all beyond the areas of hard coal exploitation) – Jas-Mos 1, Makoszowy and Śląsk-Pole Panewnickie; and new documentations with recalculated resources for Pniówek and Sośnica deposits. The highest growth of resources was noted in 2019 (by 109.55 bnm³ in comparison with 2018) – due to 1 new deposit documented beyond the areas of hard coal exploitation (Dankowice 1) and 4 new pieces of documentation with recalculated resources for the Murcki, Wesoła, Zabrze-Bielszowice and Ziemowit deposits. In 2020, the resources dropped by 2.32 bnm³ as there were no new deposit documented and 2 deposits (Marcel and Rydułtowy) were crossed out from "The balance…". Emissions from the ventilation systems and output also contributed to the decline in resources.

Output of CBM in the presented period was changing significantly – from the lowest level recorded in 1994 (205.51 Mm³) to the highest noted in 2008 (586.75 Mm³). The declining tendency was visible in the 1992–1994, 1999–2001 and 2009–2010 periods, whereas more intensive growth trends could be seen in the 2002–2008 and 2011–2016 periods. The last 5 years (2016–2020) brought about quite a stable level of output – within the range of 315.09–357.09 Mm³.

8.3. Crude oil

D. Brzeziński, M. Czapigo-Czapla, K. Wójcik

In 2020, there were 87 crude oil fields documented in Poland, including 29 fields situated in the Carpathians, 12 at the Carpathian Foreland (in the Carpathian Foredeep), 44 within the Polish Lowland and 2 in the Polish Economic Zone of the Baltic Sea (Plate 1). In a regional sense, similarly to natural gas fields, crude oil fields have been balanced in the present elaboration and are annually presented in "The balance…". The oil fields occurring in the Carpathians and Carpathian Foreland have had a long history, as these are the areas of the world's oldest crude oil mining. However, currently these fields have almost been depleted. Currently, the Polish oil fields of greatest economic importance are situated on the Polish Lowland.

In 2020, exploitable resources of all documented crude oil fields amounted to 21,725.89 kt of crude oil, whereas anticipated sub-economic resources contributed an additional 400.25 kt. In comparison to the previous year, the total resources (anticipated economic and anticipated sub-economic) decreased by 923.16 kt (Fig. 8.3.1). Exploitable resources within exploited crude oil and condensate fields were equal to 20,442.02 kt, accounting for 92.4% of the total exploitable resources (anticipated economic and anticipated sub-economic), whereas economic resources – 12,032.50 kt (data above mentioned, taking into account the distribution of regional resources and the state of development of the fields can be found in Tab. 8.3.1). Crude oil and condensate output in 2020 amounted to 911.43 kt and decreased by 25.33 kt year to year (Fig. 8.3.1).

Hydrocarbon field occurrences in Poland, their origin, age and the volume of their resources result directly from the geological structure and tectonic evolution of our country. The Outer Carpathians and the Carpathian Foreland constitute the separate – Southern Petroleum Province, whereas the Polish Lowland and the Polish Economic Zone of the Baltic Sea are divided into 3 provinces – the Northern, Eastern and Western Provinces (Plate 1; Fig. 8.3.2).

In the Outer Carpathians, crude oil accumulations occur within structural traps, less often within structural-lithological traps (mainly in fields of a layered type with surrounding water) in the flysch formations of the Magura, Fore-Magura/Dukla, Silesian, Sub-Silesian and Skole units and in the Paleozoic of the Małopolska Block – the basement of Carpathian units.

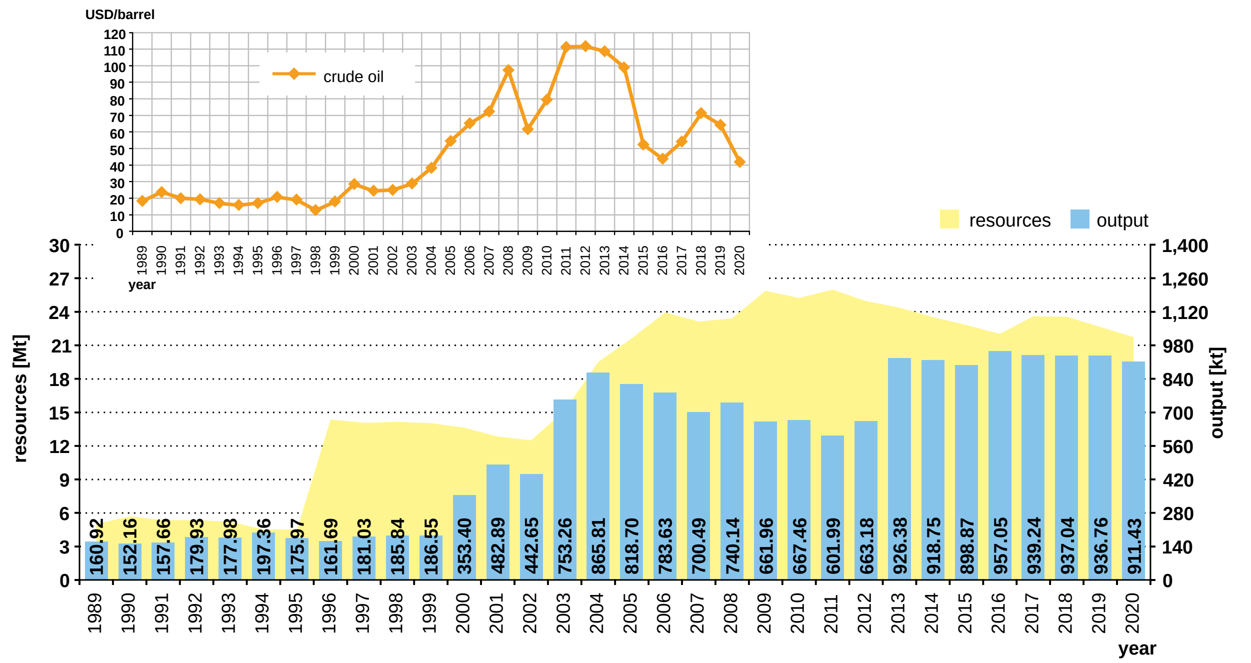


Figure 8.3.1. Crude oil anticipated economic resources and output, and annual prices in 1989–2020 (spot prices of Brent oil)

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to BP Statistical Review of World Energy 2021/70th edition

Table 8.3.1. Crude oil resources [kt]

total
crude oil
condensate

	Number of fields	Exploitable resources				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B	C		
TOTAL RESOURCES	**87**	**21,725.89** ***19,517.63*** ***2,208.26***	**13,006.14** ***12,982.56*** ***23.58***	**8,719.75** ***6,535.07*** ***2,184.68***	**400.25** ***400.25*** –	**12,032.50** ***11,461.60*** ***570.90***
Including resources of exploited fields						
TOTAL	57	20,436.35 *19,112.91* *1,323.44*	12,959.60 *12,959.60* –	7,476.75 *6,153.31* *1,323.44*	5.67 *5.67* –	11,397.46 *11,343.56* *53.90*
Baltic Sea	2	6,149.06 *6,149.06* –	6,111.84 *6,111.84* –	37.22 *37.22* –	–	5,413.49 *5,413.49* –
Carpathians	22	626.47 *626.47* –	563.49 *563.49* –	62.98 *62.98* –	5.67 *5.67* –	184.10 *184.10* –
Polish Lowland	27	13,346.62 *12,023.18* *1,323.44*	6,113.18 *6,113.18* –	7,233.44 *5,910.00* *1,323.44*	–	5,672.97 *5,619.07* *53.90*
Carparthian Foreland	6	314.20 *314.20* –	171.09 *171.09* –	143.11 *143.11* –	–	126.90 *126.90* –
Including resources of non-exploited fields						
TOTAL	7	1,163.70 *290.70* *873.00*	35.96 *16.96* *19.00*	1,127.74 *273.74* *854.00*	329.53 *329.53* –	633.50 *116.50* *517.00*
Polish Lowland	4	1,047.77 *174.77* *873.00*	35.96 *16.96* *19.00*	1,011.81 *157.81* *854.00*	–	633.50 *116.50* *517.00*
Carparthian Foreland	3	115.93 *115.93* –	–	115.93 *115.93* –	329.53 *329.53* –	–
Including abandoned fields						
TOTAL	23	125.84 *114.02* *11.82*	10.58 *6.00* *4.58*	115.26 *108.02* *7.24*	65.05 *65.05* –	1.54 *1.54* –
Carpathians	7	31.87 *30.37* *1.50*	0.96 *0.96* –	30.91 *29.41* *1.50*	12.69 *12.69* –	0.08 *0.08* –
Polish Lowland	13	89.39 *83.65* *5.74*	5.04 *5.04* –	84.35 *78.61* *5.74*	1.43 *1.43* –	1.46 *1.46* –
Carparthian Foreland	3	4.58 – *4.58*	4.58 – *4.58*	–	50.93 *50.93* –	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

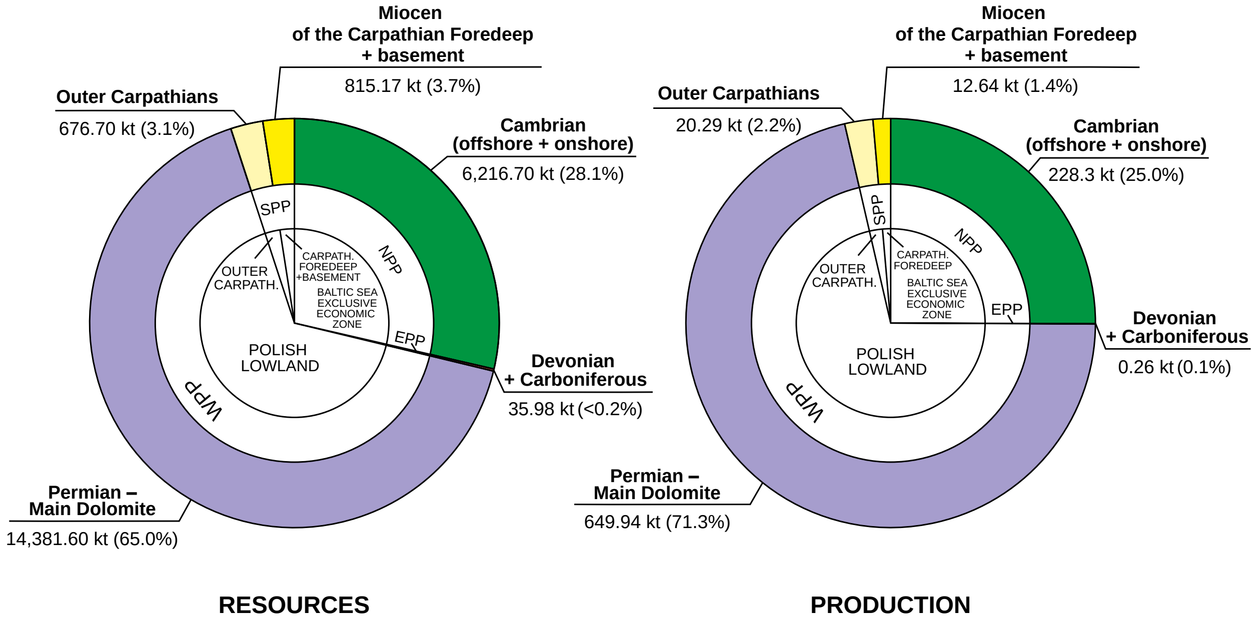


Figure 8.3.2. Structure of exploitable anticipated economic resources and output of crude oil in 2020

NPP – Northern Petroleum Province, **EPP** – Eastern Petroleum Province, **WPP** – Western Petroleum Province, **SPP** – Southern Petroleum Province
According to: own elaboration based on resources and output according to "The balance of mineral resources deposits in Poland as of 31 XII 2020" (in Polish; Szuflicki *et al.*, eds., 2021)

The Carpathian crude oil fields are mainly of an oil-gas type. Production is initially driven by the expansion of natural gas dissolved in crude oil. Crude oil density ranges from 0.750 to 0.943 g/cm^3 and the crude oil is allocated as a sulfur-free type. Paraffin content varies from 3.5 to 7.0%. The resources of Carpathian oil fields are generally minor, depending on a size and a character of the structures in which they occur – mainly in anticlines near faults. The resources of Carpathian fields have been significantly exhausted as the result of many years of exploitation: currently there are 29 fields documented with exploitable resources equal to 676.70 kt, accounting for 3.1% of total domestic resources (Tab. 8.3.1; Fig. 8.3.2). Prospective resources of crude oil in conventional accumulations of the Outer Carpathians and their basement are assessed at about 124.2 Mt (Feldman-Olszewska *et al.*, 2020a). In the Carpathian Foreland, crude oil fields occur in the autochthonous Miocene of the Carpathian Foredeep, however mainly in its Carboniferous, Jurassic, and Cretaceous basement. Most of these fields are of a layer type, with stratigraphic, lithological or tectonical shielding. Crude oil from this region belongs to a group of light and medium oils (with density ranging from 0.811 to 0.846 g/cm^3). Paraffin content varies from 2.32 to 9.37% and sulfur content from 0.45 to 0.85% on average. Currently, there are 12 crude oil fields documented in the Carpathian Foreland, with total resources equal to 815.17 kt, accounting for 3.7% of total domestic resources (Tab. 8.3.1; Fig. 8.3.2). In turn, prospective resources of crude oil in conventional accumulations of the Carpathian Foreland, amount to about 0.6 Mt (Feldman-Olszewska *et al.*, 2020a). In the Outer Carpathians and the Carpathian Foreland, some crude oil fields contain dissolved gas components, forming oil condensate (Łąkta and Słopniec fields).

The western part of the Polish Lowland, that is the Fore-Sudetic, Wielkopolska and Western Pomerania regions, together with the western part of the Polish Economic Zone of the Baltic Sea, form the separate – Western Petroleum Province. In a structural sense, these are regions located west of the East European Platform, in which natural gas and crude oil field origin is connected with the evolution of the Variscan orogen and its Permian-Mesozoic sedimentary cover. Crude oil accumulations occur here in the Permian/Zechstein – in the Main Dolomite. These oils are of a medium paraffin type, with paraffin content ranging from 4.3 to 7.4%, sulfur content slightly above 1% and density within a range of 0.857–0.870 g/cm^3. The majority of these fields are of a massive type, with passive underlying water and with a gas cap expansion drive mechanism. In the Western Petroleum Province, the largest Polish crude oil field can be found – the Barnówko-Mostno-Buszewo (BMB), located near the city of Gorzów Wielkopolski. Its resources of crude oil were found to be twice the size of total domestic resources before its discovery. Within the Western Petroleum Province, there are also other fields rich in resources-occurring in: Lubiatów, Grotów (crude oil fields), and Cychry, Krobielewko, Jastrzębsko and Antonin 1 (condensate fields). Total exploitable resources of all 38 crude oil and condensate fields within the Main Dolomite amount to 14,381.60 kt and account for 65.0% of total domestic resources (Fig. 8.3.2). Another 235 Mt constitute prospective resources (Feldman-Olszewska *et al.*, 2020a).

The northern part of the Polish Lowland together with the eastern part of the Polish Economic Zone of the Baltic Sea constitute the Northern Petroleum Province of Poland. These regions are located on the East European Platform and their hydrocarbons field origin is connected with the geological evolution of the Peribaltic Syneclise. Conventional crude oil accumulations occur within the Cambrian – in 2 fields located on the Baltic Sea (B 3 and B 8) and 4 fields located onshore (of them only 1 field – Żarnowiec W – contains condensate). Total exploitable resources of the aforementioned fields amount to 6,216.70 kt of crude oil and condensate (28.1% of total domestic resources; Fig. 8.3.2), of which 6,149.06 kt is documented in 2 fields located off-shore. Prospective resources in conventional accumulations within the Cambrian are assessed to add a further 1.1 Mt (Feldman-Olszewska *et al.*, 2020a). The Cambrian of the Baltic Sea area is also treated as the most prospective region for the occurrence of unconventional crude oil accumulations (tight oil; Wójcicki *et al.*, 2020).

In the eastern part of the Polish Lowland – the Podlasie-Lublin region – the Eastern Petroleum Province was distinguished. In this area hydrocarbon fields developed in the Devonian-Carboniferous sedimentary cover of the East European Platform margin area. There are 2 crude oil fields documented – within the Devonian (Glinnik field) and Carboniferous (Stężyca field) strata, respectively. Their total exploitable resources are equal to 35.98 kt, accounting for <0.2% of total domestic resources (Fig. 8.3.2). Prognostic resources of a region were assessed at a further 19.36 Mt (Feldman-Olszewska *et al.*, 2020a).

The Northern- and Eastern-Polish Petroleum Provinces, that are the part of the Polish Lowland structurally corresponding to the East European Platform, are also the prospective areas for the occurrence of unconventional crude oil field within the Lower Paleozoic shales (Podhalańska *et al.*, 2020a, Wójcicki *et al.*, 2020). Estimated resources of technologically exploitable crude oil within both provinces in total, calculated using a volumetric method, amount to 89.2–144.6 Mt, whereby 73.4–99.2 Mt constitute resources within the Polish Economic Zone of the Baltic Sea.

Between 1989 and 1995, anticipated economic exploitable resources of crude oil were quite stable (at 4.5–5.7 Mt). Then, in 1996, there was rapid growth recorded to 14.3 Mt as a result of the largest crude oil field discovery in Poland – the BMB, within the Main Dolomite on the Polish Lowland, with its resources initially assessed at 10.14 Mt. Up to 2002, the resources were decreasing systematically as the result of exploitation. Next, they increased from 12.51 Mt in 2003 to 23.95 Mt in 2006. It was mainly the result of documenting new fields within the Main Dolomite: Lubiatów field in 2003 (initially 4.39 Mt, followed by a 1.02 Mt increase in 2005, due to better field exploration), Grotów field in 2005 (1.83 Mt), Dzieduszyce field in 2006 (0.52 Mt) and Michorzewo field in 2006 (0.04 Mt); it also resulted from including into "The balance…" the resources of the Cambrian fields of the Polish Economic Zone of the Baltic Sea (B 3 field in 2003 – 3.13 Mt and B 8 field in 2004 – 0.75 Mt). During 2003–2006 another increase in resources was recorded for the BMB field (by 2.06 Mt). The next 2 years (2007–2008) brought stabilization in resources – new field documentation and better exploration of already documented fields compensated the decreases caused by exploitation. Another significant increase in resources was noted in 2009 – as a result of better exploration of the B 8 field within the Cambrian of the Polish Economic Zone of the Baltic Sea (increase by 2.84 Mt). The following 2 years were, once again, characterized by a stabilization of domestic resources – in 2011 2 new fields were documented within the Main Dolomite – Gajewo field (0.05 Mt) and Kamień Mały field (0.71 Mt). Concordantly, crude oil resources achieved the largest volume in the entire 30-year period – 25.99 Mt. Other fields were documented in 2013 and 2015, within the Mesozoic basement of the Carpathian Foredeep – Wierzchosławice, and within the Main Dolomite – Sieraków, respectively. Total resources of these fields were equal to 0.32 Mt. Since 2012, the volume of resources was systematically decreasing, on average by 3.4% annually. This tendency was stopped in 2017, due to an additional assessment of resources of the fields within the Polish Economic Zone of the Baltic Sea (the B 3 field – an increase of 1.25Mt, the B 8 field – an increase of 1.31 Mt). In the last 3 years, resources have reverted to following a declining tendency – on average by 2.8% annually, in spite of 2 new fields being documented within the Main Dolomite – Krobielewko in 2018 (0.85 Mt) and Połęcko (0.05 Mt) in 2019.

Until 1999, crude oil output was very stable and varied only within the range of 152–197 kt annually (174 kt on the average). In 2000–2004 exploitation rapidly increased up to nearly 866 kt in 2004 – as a result of starting production from the BMB field and from including offshore (Baltic) field (the B 3 field) into "The balance…". Then, output was systematically decreasing from 818.70 kt in 2005 to 601.99 kt in 2011 (with only 1 year of growth in 2008, as the result of more intensive exploitation of the B 8 field). Only in 2012–2013 there was significant output increase recorded (by 10 and 40%, respectively) due to more intensive exploitation in the Lubiatów field. Since 2013 output volumes stabilized with slight decreasing tendency about 1.3% annually. In 2016 annual growth was recorded at 6.5% – to 957.05 kt, the highest level in the analyzed 30-year period. In 2020, the exploitation of onshore fields accounted for 75% of total domestic output (of which 71.3% of total output came from the Main Dolomite of the Polish Lowland, 0.1% from the Devonian-Carboniferous units in the Lublin area within the Eastern Petroleum Province, with negligible involvement of the Cambrian fields within the onshore part of the Northern Petroleum Province; output from the Outer Carpathians and Carpathian Foreland fields accounted for 2.2 and 1.4%, respectively; Fig. 8.3.2), whereas the remaining 25% falls to the fields if the Polish Economic Zone of the Baltic Sea. Fields of the largest output volume in 2020 were as follows: BMB (311.14 kt) and Lubiatów (263.31 kt) with production coming from the Main Dolomite, and B 8 (157.64 kt) and B 3 (70.26 kt) with production coming from the Cambrian of the Polish Economic Zone of the Baltic Sea.

Crude oil output from anticipated sub-economic resources is negligible and in 2020 amounted to 0.25 kt (0.03% of total domestic output). There is a declining tendency in the participation of this kind of exploitation in domestic volumes has been occurring continuously for a decade.

Crude oil prices remained in the range of 10–30 USD/barrel and started to increase to achieve a price of almost 100 USD/barrel in 2004 (Fig. 8.3.1). The main reasons were: the War on Terrorism in the Middle East, uncertainties on the Russian market (nationalization of the private corporations), the situation in Venezuela and Nigeria. Growing global demand was also an important factor. The 2009 decrease was caused by a global economy crisis. During it, prices rose, following an OPEC cut of 4.2 Mb/d in January of 2009, and due to rising demand in Asia. In late February 2011, prices jumped as a consequence of the loss of Libyan exports in the face of the Libyan civil war. The sustained excess of crude oil supply over global demand resulted in much lower crude oil prices in 2015 and 2016 – they fell to the level much below the 2009 average. In 2017, the average price increased to 54.19 USD/barrel, due to production cuts – it was the first annual increase since 2012. 2018 was the second consecutive year during which prices grew to 71.31 USD/barrel. This was a result of a decrease in OPEC production (by 0.3 Mb/d), additionally stimulated by a growth in demand. The following year brought a decrease in prices to 64.21 USD/barrel, mainly due to OECD demand being reduced by 290,000 b/d – the first decline since 2014. Last year saw the prices fall to an average of 41.84 USD/barrel – the lowest price since 2004. This was the result of the ongoing COVID crisis – especially in the first part of the year (up until April of 2020) when global oil consumption collapsed to the point, using less than 20 Mb/d when compared to pre-COVID-19 usage.

8.4. Hard coal

A. Malon, M. Młynarczyk, M. Tymiński

Polish hard coal deposits belong to the Carboniferous Euro-American coal province. In Europe, this province forms 2 belts of coal basins: a belt of paralic coal basins that originated near the sea in depressions along the front of the Variscan fold belt, which was forming during this period, and a belt of limnic basins, with coals accumulated in closed basins and intermontane depressions with disconnected internal river systems. In Poland, Carboniferous coal deposits occur in 3 basins (Plate 2): 2 basins of the paralic type – the USCB and LCB, and 1 of the limnic type – the LSCB. The exploitation of coal is being carried out in 2 of these basins (the USCB and the LCB). In the third of them (LSCB), exploitation was run in the past and all five of its coal mines were abandoned about 20 years ago. Nevertheless, over the last 7 years, exploration was carried out in said basin, which resulted in the geological documentation of 2 deposits: Nowa Ruda Pole Piast Wacław-Lech in 2014 and Heddi II in 2016.

An exploitation concession has also been granted for one of these coal deposit (Heddi II), which is now in the construction phase of a mining plant.

The USCB is one of the major coal basins in Poland. This is the area where all of the operating coal mines are situated, with the exception of 1 mine – Bogdanka. The total area of Polish part of the USCB is estimated to cover about 5,600 km^2, of which the area of documented deposits amounts to over 3,045 km^2. At present, USCB anticipated economic resources account for approximately 79.99% of hard coal domestic resources in Poland.

In the case of the LCB, the other major basin, the total area of the defined prospective deposits is assumed to be about 4,730 km^2, of which documented deposits covers the area of about 1,200 km^2. The only active mine in the basin is Bogdanka, currently exploiting 2 deposits (Bogdanka and Lubelskie Zagłębie Węglowe - obszar K-3), whereas 1 deposit (Ostrów) is currently being prepared for exploitation. These 3 deposits cover an area of about 171 km^2 and accounts for 14.25% of the LCB total area.

Mining operations in the LSCB were phased out in the year 2000, followed by closure works in the last active coal field – Słupiec (of the Nowa Ruda mine). Coal production ceased in the LSCB due to difficult geological-mining conditions, which resulted in clearly excessive exploitation costs. The anticipated economic resources that met the anticipated economic parameters left in the abandoned mining fields of the LSCB were reclassified as anticipated sub-economic resources. Their amount was estimated at about 369 Mt. In 2011, by order of the Ministry of the Environment, there was a new verification of the remaining coal resources in the LCSB. At that time, new geological documentation, with recalculated resources for 7 deposits, was prepared and most of the anticipated sub-economic resources were reclassified as anticipated economic resources. Currently, combining the old and newly documented deposits (in 2014 and in 2016), the anticipated economic resources of the LSCB are estimated at 423.98 Mt.

In the latest edition of "The balance of prospective mineral resources of Poland", the assessment of prospective hard coal resources in Poland was updated (Jureczka *et al.*, 2020). The following documentation depth criteria were adopted: the LSCB – 1,250 m for prospective resources (prognostic resources were not assessed); the USCB – 1,250/1,300 m, both for prospective and prognostic resources; the LCB – 1,000 m for prognostic resources and 1,250 m for prospective resources. At the same time, resources were calculated based on the current parameter limits that define a hard coal deposit and its boundaries, however a minimum bed thickness was accepted as 1.0 m due to current technological and economic exploitation conditions. Only for the LCB, in the border area with the Lwów-Wołyń Basin, in which beds with a thickness of 0.6 m are being exploited, such thickness was maintained as the minimal. The total prognostic resources of hard coal in Poland as of the end of 2018 amounted to 17,004.82 Mt and prospective resources – 26,914.19 Mt. In the particular coal basins resources were recorded as follows: the LSCB – 100.00 Mt of prospective resources (of a hypothetical character); the USCB – 4,616.17 Mt of prognostic resources and 20,926.58 Mt of prospective resources; the LCB – 12,388.65 Mt of prognostic resources and 5,887.61 Mt of prospective resources.

Within the USCB and the LSCB, all technological types of hard coal occur – from steam coals (type 31) to coking coals (type 38) and sometimes (mainly in the LSCB) anthracite (type 41). Mainly steam coal up to gas-coke quality coal occurs (types 31–34) in the LCB. In the USCB deposits the mean ash content varies from 4.00 to 23.00% and total sulfur content from 0.40 to 9.00%, whereas in the LSCB deposits from 10.10 to 38.77% and from 0.69 to 1.61%, respectively. The mean ash content in the LCB deposits falls within the range of 6.15–20.71% and sulfur content 1.28–3.12%.

Hard coal total resources and the current state of their exploration and development in Poland are presented in Table 8.4.1. Documented anticipated economic hard coal resources as of the end of 2020 amounted to 64,422.38 Mt. Steam coals represent almost ¾ of the resources (70.75%) and coking coals – above ¼ (28.03%), whereas the participation of other types of coals remains negligible (1.22%). The resources from exploited hard coal deposits were estimated at 28,409.26 Mt, accounting for 44.10% of the total anticipated economic resources. The anticipated economic resources covered by a detailed exploration (category A, B, C_1) totaled 29,951.41 Mt, accounting for 46.49% of the total anticipated economic resources. The resources documented in the C_2 and D categories (in less detail) accounted for 50.52% (32,545.69 Mt) and 2.99% (1,925.29 Mt), respectively. Anticipated sub-economic resources are divided into 2 groups: A – proper anticipated sub-economic resources and B – resources meeting required parameter limits that define a deposit, but classified as sub-economic due to difficult geological conditions. Anticipated sub-economic resources in group B were approved until 2001.

Table 8.4.1. Hard coal resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic group A group B	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**163**	**64,422.38**	**6,413.32**	**23,538.09**	**32,545.69**	**1,925.29**	**12,825.33** **525.68**	**4,809.84**
Steam coal		45,578.50	4,092.62	15,652.47	24,691.73	1,141.68	9,645.91 328.28	2,712.15
Coking coal		18,058.53	2,312.80	7,841.11	7,751.91	152.71	3,142.59 197.40	2,097.57
Other coals		785.35	7.90	44.51	102.04	630.90	36.84 –	0.11
Including resources of exploited deposits								
TOTAL	49	28,409.26	4,436.68	13,881.38	9,830.47	260.73	2,729.19 324.75	4,388.72
Steam coal		16,548.95	2,566.64	8,575.59	5,263.56	143.16	1,935.41 251.24	2,364.88
Coking coal		11,855.90	1,869.97	5,305.74	4,562.62	117.57	793.78 73.51	2,023.83
Other coals		4.41	0.07	0.05	4.29	–	–	–
1. Deposits of operating mines	41	25,418.33	4,202.24	12,321.86	8,720.98	173.25	2,259.60 143.07	3,882.33
Steam coal		14,792.02	2,405.27	7,602.09	4,728.98	55.68	1,793.35 72.61	2,062.42
Coking coal		10,624.01	1,796.91	4,719.72	3,989.81	117.57	466.25 70.46	1,819.91
Other coals		2.30	0.07	0.05	2.19	–	–	–
2. Deposits exploited temporarily	5	519.48	146.52	131.68	153.80	87.48	150.21 181.68	52.46
Steam coal		498.85	143.48	125.92	141.98	87.48	141.82 178.63	51.65
Coking coal		20.63	3.04	5.77	11.82	–	8.38 3.05	0.81
Other coals		–	–	–	–	–	–	–
3. Mines during preparation process	3	2,471.45	87.92	1,427.84	955.69	–	319.39 –	453.93
Steam coal		1,258.08	17.90	847.59	392.60	–	0.24 –	250.82
Coking coal		1,211.27	70.02	580.26	560.99	–	319.15 –	203.12
Other coals		2.11	–	–	2.11	–	–	–
Including resources of non-exploited deposits								
TOTAL	59	30,585.70	486.05	7,463.31	20,971.79	1,664.56	8,516.61 199.85	347.01
Steam coal		25,429.63	459.49	5,502.83	18,468.79	998.52	6,802.49 76.66	330.24
Coking coal		4,516.78	26.27	1,954.54	2,500.83	35.14	1,713.84 123.18	16.66
Other coals		639.29	0.29	5.93	2.17	630.90	0.28 –	0.11

Table 8.4.1. Cont.

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic group A / group B	
		Total	A+B	C_1	C_2	D		
1. Deposits covered by detailed exploration	41	15,519.66	486.05	7,463.31	7,387.06	183.24	2,006.76 / 199.85	347.01
Steam coal		12,184.21	459.49	5,502.83	6,039.38	182.51	1,204.01 / 76.66	330.24
Coking coal		3,327.05	26.27	1,954.54	1,345.51	0.73	802.47 / 123.18	16.66
Other coals		8.39	0.29	5.93	2.17	–	0.28 / –	0.11
2. Deposits covered by preliminary exploration	18	15,066.04	–	–	13,584.73	1,481.31	6,509.85 / –	–
Steam coal		13,245.42	–	–	12,429.41	816.01	5,598.48 / –	–
Coking coal		1,189.72	–	–	1,155.32	34.41	911.38 / –	–
Other coals		630.90	–	–	–	630.90	–	–
Including abandoned deposits								
TOTAL	55	5,427.42	1,490.59	2,193.40	1,743.43	–	1,579.53 / 1.09	74.11
Coking coal		3,599.92	1,066.49	1,574.05	959.38	–	908.01 / 0.38	17.03
Other coals		1,685.86	416.56	580.83	688.47	–	634.96 / 0.71	57.08
Steam coal		141.65	7.54	38.53	95.58	–	36.56 / –	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

Economic resources of mines calculated in deposit development plans as of the end of 2020 amounted to 4,809.84 Mt, increasing by 30,636 kt (or by 0.64%) in comparison to 2019. The changes in resources were the result of new deposit development plans, supplements for such plans, and exploitation and losses in production. The economic resources are currently calculated within a reference frame of the duration of a concession for hard coal exploitation, thus their real volume in some deposits may be significantly bigger. An update of the volume of economic resources will be regularly carried out in consecutive deposit development plans. According to data supplied by the operators of individual hard coal mines – as of the end of 2020 – the total output amounted to 48,156 kt.

Figure 8.4.1 shows changes in a magnitude of resources and output in the 1989–2020 period. Polish coal mines have been subject to restructuring and rationalization from the beginning of the transformation process of the national economy, at the end of the 1980's. In consecutive years, total anticipated economic resources of coal began to decrease steadily due to exploitation and associated mining losses, and, on a much larger scale, due to verification and reclassification of resources following adjustments to the mining sector to the requirements of a free-market economy. These factors resulted in a decrease of coal resources from 65.8 bnt in 1989 to 42.0 bnt in 2006 (the lowest amount in the presented period). Resources remained in the range of about 43–44 bnt over the next 4 years and then started to increase again. In 2011, this was mainly a result of the verification of remaining resources in unused (abandoned) deposits (38 new pieces of documentation for already documented deposits was elaborated) and, therefore, reclassification of coal resources from anticipated sub-economic group to anticipated economic resources group. Resources slightly decreased in 2012 and then in 2013–2015 period

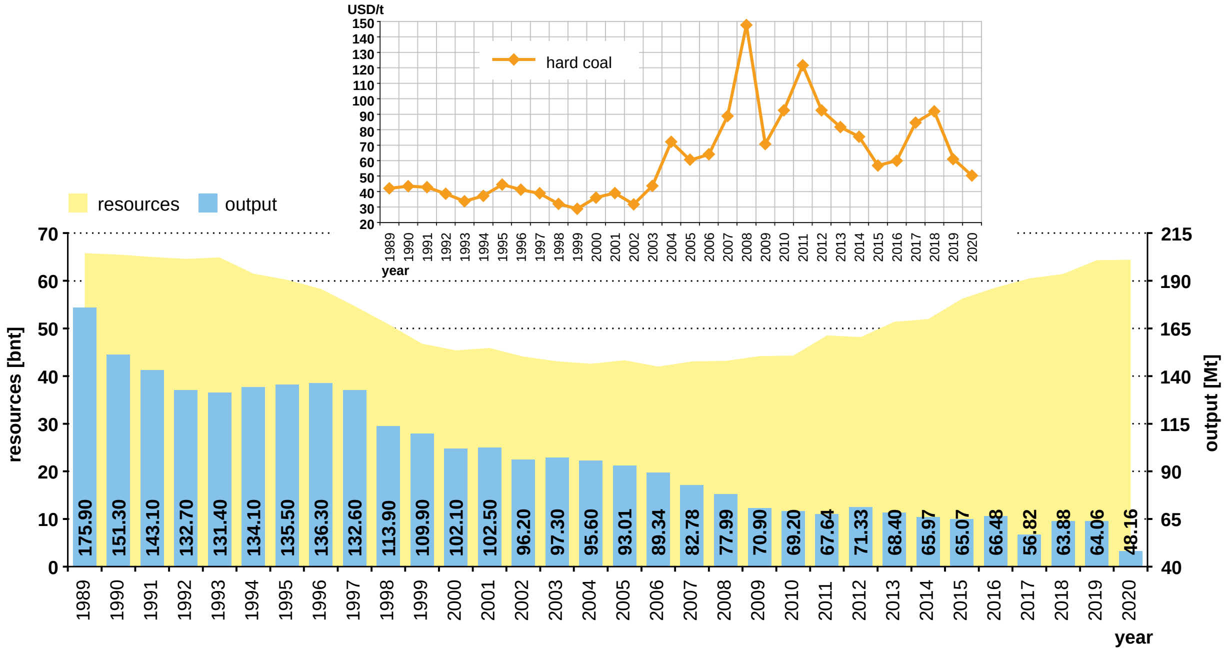


Figure 8.4.1. Hard coal anticipated economic resources, output and annual prices in 1989–2020 (steam coal, Northwest Europe marker price)

Resources and output according to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to BP Statistical Review of World Energy 2021/70th edition – source: IHS Markit Northwest Europe – prices for 1989–2000 are the average of the monthly marker, 2001–2020 the average of weekly prices

grew again due to: documentation of 16 new deposits (with total resources of 7,562.42 Mt) – 5 in 2013 (Anna 1, Brzezinka 1, Dąb, Oświęcim-Polanka 1 and Śmiłowice), 5 in 2014 (Nowa Ruda Pole Piast Rejon Wacław-Lech, Barbara-Chorzów 2, Brzezinka 3, Bzie-Dębina 2 and Jan Kanty 2) and 6 in 2015 (Jan Kanty-Szczakowa, Powstańców Śląskich 1, Siersza 2, Studzienice 1, Żory-Suszec 1 and Lublin). The Lublin deposit having the largest resources (+2,277.85 Mt) and was the only one documented beyond the USCB (in the LCB) new documentations with larger recalculated resources for 18 deposits (with total resource change of 3,328.36 Mt), including the Borynia deposit with the largest change (+635.66 Mt). There were also 9 deposits crossed out from the register ("The balance...") in 2013–2015, new documentations with lesser resources recalculated for 17 deposits and exploitation and losses from exploited deposits. These factors significantly reduced potential growth and resources ultimately amounted to 56.22 bnt in 2015 (10.8% more than in 2014).

In comparison with 2015, the 2016–2020 period brought another anticipated economic resources growth – by a total magnitude of 8,201.90 Mt (14.59%). There were following reasons for this increase: documentation of 10 deposits (with total resources equal 5,122.95 Mt) – 4 in 2016 (Heddi II, Chwałowice 1, Imielin Północ and Marcel 1), 1 in 2017 (Rydułtowy 1), 3 in 2018 (Bobrek-Miechowice 2, Centrum 1 and Jas-Mos 1), 1 in 2019 (Dankowice 1) and 1 in 2020 (Sawin 1); new documentations with larger recalculated resources for 17 deposits (with the total resources growth equal 6,090.53 Mt). There were also new documentations with lower resources recalculated for 16 deposits (with the total resources drop by 2,721.17 Mt); other resources decrease was caused by exploitation (about 299.40 Mt in 2016–2020 period) and mining losses. In 2020 solely, the anticipated economic resources increased by 92.54 Mt in comparison with 2019.

Restructuring and nationalization were also main factors affecting hard coal output volume that decreased from 175.90 Mt in 1989 to 67.64 Mt at the end of 2011 (Fig. 8.4.1). In 2012, output exceeded the level of 71 Mt as a result of more intensive exploitation from 17 deposits. In the next 3 years (2013–2015) it has been decreasing systematically to about 65 Mt. The 2016–2020 period brought some fluctuations in the hard coal output. After the slight growth in 2016, the exploitation magnitude dropped in 2017 to the level of 56.82 Mt – by 9.66 Mt

(14.53%). In 2018 the output increased by 7.06 Mt (12.43%), mainly due to the more intensive exploitation of such deposits as: Łaziska, Borynia, Halemba, despite the smaller number of the total exploited deposits. Next year was characterized by a stable output level, whereas in 2020 the output dropped significantly – by 15.90 Mt (24.82%) – to the lowest level in the given period of time (48.16 Mt). The number of exploited deposits increased from 46 to 49, however in many of them the exploitation was much less intensive. It was the case of such deposits as: Budryk, Halemba, Jankowice, Jaworzno, Marcel 1, Piast, Staszic, Ziemowit and Bogdanka. One of the important causes of this situation was the COVID-19 pandemic.

Figure 8.4.1 also presents changes in hard coal prices at the example of steam coal imported to Europe (on the basis of the Northwest Europe marker price) in 1989–2020.

The steam coal price varied between 20 and 45 USD/t in 1989–2003 to increase rapidly in the next 2 years. After 1-year drop the prices grew to above 147 USD/t in 2008 – the highest level in the analyzed period. This growth was caused by: weather disturbances in Australia, Indonesia and China obstructing exploitation and transport as well as growing demand; supply difficulties in South Africa and Russia; increasing crude oil and gas prices and a weak position US dollar in relation to other currencies. Hard coal prices fell significantly in 2009 (due to the global economic crisis) followed by 2-year growth (mainly due to greater demand in China). Since 2012, prices have been decreasing regularly and have reached a level below 66 USD/t in 2015. The main reasons were: – decreasing demand in Europe and China and, therefore, oversupply on the international market, significant changes in the United States energy sector with shale gas playing a more important role and leaving the US with surplus hard coal that is directed to the international market and declining crude oil prices that generate lower transport costs. In 2016–2018 prices grew to the level of almost 92 USD/t – due to the growing coal consumption. The next 2 years brought the prices drops as a result of declining consumption, especially with OECD coal consumption falling to its lowest level in the data back to 1965.

8.5. Helium

D. Brzeziński, M. Czapigo-Czapla, K. Wójcik

Helium occurs as an admixture in natural gas fields on the Polish Lowland. In 2020, helium resources were assessed in 18 fields where its average content varies from 0.216 to 0.420%. Exploitable resources amounted to 24.29 Mm³ and the total recovery in course of gas denitrification from 10 exploited fields was equal to 0.71 Mm³ (Tab. 8.5.1 and Fig. 8.5.1). The given volume does not include the recovery from such natural gas fields in which helium has not been documented as a raw material (natural gas fields containing anticipated sub-economic admixtures of helium i.e. below 0.2% of He). The total pure helium production by the Polish Oil and Gas Company (in Polish: PGNiG) – Odolanów Branch, from the exploited natural gas in Poland, amounted to 2.92 Mm³ in 2020.

Helium fields occur in the southern part of the Fore-Sudetic Monocline, within the Zielona Góra–Rawicz–Odolanów area and are developed in the Permian horizons – Upper Rotliegend, Zechstein Limestone and Main Dolomite. The Trzebusz field is an exception, in which, in 2020, helium was documented as an admixture accompanying natural gas resources accumulated in the Carboniferous sandstones in Western Pomerania (an averaged helium content in natural gas is 0.246% by volume). Prospective resources of helium in the mentioned above horizons amount to about 34.68 Mm³ in total and were assessed on a basis of 30 natural gas field analyses – in which helium presence was detected, however the resources have not yet been documented (Ługiewicz-Mołas *et al.*, 2020).

In the last 30 years, helium resources have been systematically decreasing (Fig. 8.5.1) – by about 4% on average annually. A similar tendency has been recorded for output volumes – an annual decrease has been quite stable at about 7%. The resources and recovery declines resulted mainly from exploitation and reclassification of resources of the largest field – Bogdaj-Uciechów, in which gases are accumulated in the Zechstein Limestone and Upper Rotliegend on the Polish Lowland. In 2020, the resources of this field accounted for almost 45% of total domestic resources, systematically decreasing from 37.28 Mm³ in 1989, through 18.75 Mm³ in 2000, 13.94 Mm³ in 2010, to the current amount of 10.89 Mm³. In the 1989–2020 period, the Bogdaj-

Table 8.5.1. Helium resources [Mm³]

	Number of fields	Exploitable resources			
		Anticipated economic			Anticipated sub-economic
		Total	A+B	C	
TOTAL RESOURCES	**18**	**24.29**	**21.73**	**2.56**	–
including:					
exploited fields	10	19.98	18.50	1.48	
non-exploited fields	8	4.31	3.23	1.08	

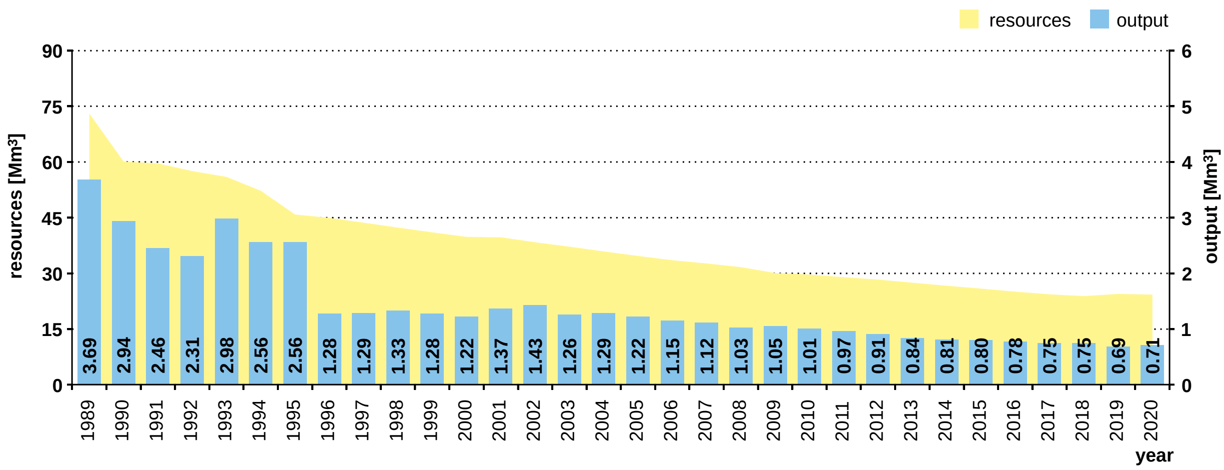


Figure 8.5.1. Helium anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Uciechów field contributed about 18.70 Mm³ of recovered helium and its output share in domestic helium recovery was being maintained between 34 and 58% (41% on average). During the analyzed period, helium was also intensively sourced from other Rotliegend fields on the Polish Lowland – Wilków (1989–2020 – about 7.62 Mm³ in total) and Grochowiec (1997–2020 – about 3.71 Mm³ in total). In 2020, these fields accounted for 23% and 15% of domestic helium recovery, respectively.

8.6. High-nitrogen natural gas (HNNG)

D. Brzeziński, M. Czapigo-Czapla, K. Wójcik

Up until today, there have been 2 HNNG fields documented in Poland. These are Cychry and Sulęcin fields, located on the Polish Lowland (Plate 1), characterized by nitrogen content over 90%. In 2020, total exploitable resources of these fields amounted to 14.72 bnm³ (Tab. 8.6.1), however exploitation has only been carried out from the Cychry field and was estimated at 32.99 Mm³.

Both of the above-mentioned fields have HNNG accumulated within the Permian carbonate sediments – in the Zechstein Main Dolomite. The Cychry field was discovered in 1973. In the late 90's nitrogen and accompanying hydrocarbons from the Cychry field began to be used as a so-called "calorific value adjusters" – as a result of preparing development plans for newly documented natural gas fields: Barnówko-Mostno-Buszewo (BMB) and Różańsko. In the 1997–2020 period, production of gas from the Cychry field exploited an estimated total of about 663.12 Mm³ (the largest volume was recorded in 1999 – 102.67 Mm³; in the last decade, output levels were significantly lower in magnitude: 4.30–15.46 Mm³ annually, and then rapidly grew in 2019–2020 to the current volume).

Table 8.6.1. High-nitrogen natural gas resources [Mm^3]

	Number of fields	Exploitable resources				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B	C		
TOTAL RESOURCES	**2**	**14,720.88**	**3,300.00**	**11,420.88**	**–**	**834.78**
Including resources of exploited fields						
Polish Lowland – Cychry field	1	11,420.88	–	11,420.88	–	834.78
Including resources of non-exploited fields						
Polish Lowland – Sulęcin field	1	3,300.00	3,300.00	–	–	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

HNNG can be used for the production of liquid nitrogen, but more often it is used to adjust the chemical composition of natural gas in the domestic distribution network. The latter purpose especially involves gas with a nitrogen content exceeding 70%. Nevertheless, fields with lower nitrogen content are not differentiated as a separate group of HNNG fields.

8.7. Natural gas

D. Brzeziński, M. Czapigo-Czapla, K. Wójcik

In 2020, there were 306 natural gas fields documented in Poland. These fields occur within 4 regions – in the Outer Carpathians, Carpathian Foreland, Polish Lowland and Polish Economic Zone of the Baltic Sea (Plate 1). In a regional sense, similar to crude oil fields, natural gas fields have been balanced in the present report and annually presented in other "The balance…" reports.

The exploitable resources of natural gas within all documented fields, as of the end of 2020, were estimated at 143.92 bnm³ (anticipated economic and anticipated subeconomic resources in total) and decreased by 0.33 bnm³ in comparison with the previous year (Fig. 8.7.1). Exploitable resources within the exploited fields amounted to 95.81 Mm³ (66.6% of total exploitable resources in Poland), whereas economic resources – 73.51 bnm³. In 2020 natural gas output amounted to 4.934 bnm³ and fell by 0.042 bnm³ year-over-year (Fig. 8.7.1).

Table 8.7.1 shows exploitable resources of natural gas exploited from gas, crude oil and condensate fields, with various methane contents. Data are not converted to those of high methane gas (high methane gas = extracted resources × combustion heat of real gas/combustion heat of high methane gas, that is about 34 MJ/m³).

Similar to crude oil fields, the areas of the Outer Carpathians and Carpathian Foreland were included into the Southern Petroleum Province, whereas the Polish Lowland and the Polish Economic Zone of the Baltic Sea are divided into 3 following and separately described provinces – the Northern, Eastern and Western Provinces (Fig. 8.7.2; Plate 1).

In the Outer Carpathians, natural gas occurs within structural traps in the Cretaceous and Paleogene flysch formations of the Magura, Fore-Magura/Dukla, Silesian, Sub-Silesian and Skole units, and in the Paleozoic formations of the Małopolska and Upper Silesian Blocks – in the basement of the Carpathians units. Natural gas occurs in the form of unassociated fields, as well as accompanying crude oil or oil condensate fields. The natural gas occurrences are characterized by a high methane content (usually over 85%), and an average nitrogen content of is a few percent. Total exploitable resources of natural gas in the 35 Carpathians fields amount to 1.561 bnm³, which accounts for 1.1% of Polish natural gas resources (Fig. 8.7.2). Prospective resources in conventional accumulations are assessed at 30.6 bnm³ (Feldman-Olszewska *et al.*, 2020a). At the Carpathian Foreland, natural gas fields occur in the autochthonous

Miocene of the Carpathian Foredeep and in the Precambrian, Cambrian, Devonian, Carboniferous, Triassic, Jurassic and Cretaceous basement. Most often, fields contain high methane natural gas with low nitrogen content. There are a few exceptions, where natural gas fields contain high nitrogen concentrations. In this region, natural gas occurs in structural-lithological multi-layered traps or, sometimes massive-type traps with gas driving mechanisms. Total exploitable resources of natural gas located in 109 fields documented within this area, amount to 31.514 bnm³, accounting for 21.9% of total domestic resources of natural gas (Fig. 8.7.2). Prospective resources in conventional accumulations are assessed at 57.1 bnm³ (Feldman-Olszewska *et al.*, 2020a).

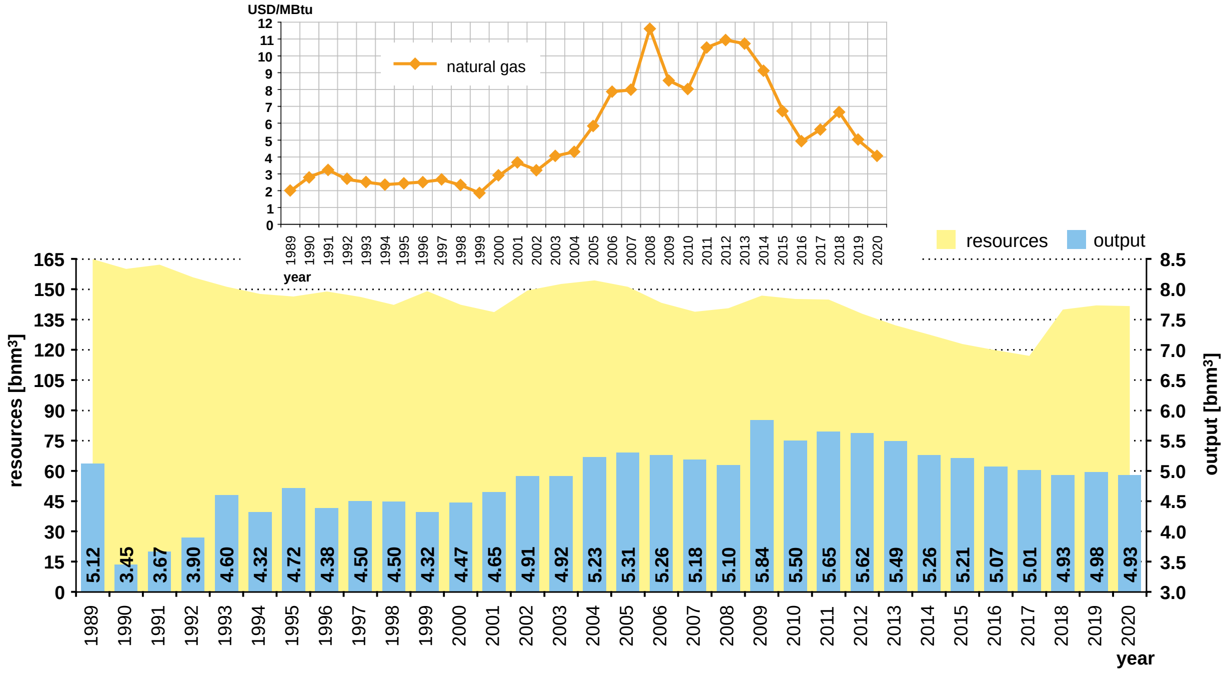


Figure 8.7.1. Anticipated economic resources and output and annual prices of natural gas in 1989–2020 (average German Import Price)

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to BP Statistical Review of World Energy 2021/70th edition – source: 1989–1990 German Federal Statistical Office, 1991–2020 German Federal Office of Economics and Export Control (BAFA)

Table 8.7.1. Natural gas resources [Mm³]

total
from oil and condensate fields
from gas fields
from PMG fields

	Number of fields	Exploitable resources				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B	C		
TOTAL RESOURCES	**306**	**141,643.38** **21,754.00** **113,183.73** **6,705.65**	**66,895.32** **6,580.75** **53,608.92** **6,705.65**	**74,748.06** **15,173.25** **59,574.81** **–**	**2,277.13** **655.18** **1,621.95** **–**	**73,514.38** **14,273.94** **59,026.42** **214.02**
Including resources of exploited fields						
TOTAL	200	95,137.63 12,397.09 76,034.89 6,705.65	60,850.76 4,779.12 49,365.99 6,705.65	34,286.87 7,617.97 26,668.90 –	669.85 650.04 19.81 –	50,825.91 9,385.58 41,226.31 214.02

Table 8.7.1. Cont.

	Number of fields	Exploitable resources				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B	C		
Baltic Sea	2	714.49 714.49 – –	710.57 710.57 – –	3.92 3.92 – –	–	631.42 631.42 – –
Carpathians	26	947.88 109.90 716.48 121.50	661.76 105.47 434.79 121.50	286.12 4.43 281.69 –	6.30 0.04 6.26 –	387.46 22.68 243.28 121.50
Polish Lowland	89	64,112.47 8,994.11 49,033.89 6,084.47	44,885.36 2,687.13 36,113.76 6,084.47	19,227.11 6,306.98 12,920.13 –	650.00 650.00 – –	37,543.69 7,313.38 30,230.31 –
Carpathian Foreland	83	29,362.79 2,578.59 26,284.52 499.68	14,593.07 1,275.95 12,817.44 499.68	14,769.72 1,302.64 13,467.08 –	13.55 – 13.55 –	12,263.34 1,418.10 10,752.72 92.52
Including resources of non-exploited fields						
TOTAL	54	44,326.57 9,191.16 35,135.41 –	5,132.27 1,800.72 3,331.55 –	39,194.30 7,390.44 31,803.86 –	1,419.75 – 1,419.75 –	21,931.72 4,888.36 17,043.36 –
Baltic Sea	3	4,464.50 4,464.50 – –	–	4,464.50 4,464.50 – –	–	4,249.23 4,249.23 – –
Carpathians	2	240.00 – 240.00 –	240.00 – 240.00 –	–	73.00 – 73.00 –	–
Polish Lowland	36	38,146.69 4,726.66 33,420.03 –	4,791.27 1,800.72 2,990.55 –	33,355.42 2,925.94 30,429.48 –	1,346.75 – 1,346.75 –	17,388.27 639.13 16,749.14 –
Carpathian Foreland	13	1,475.38 – 1,475.38 –	101.00 – 101.00 –	1,374.38 – 1,374.38 –	–	294.22 – 294.22 –
Including abandoned fields						
TOTAL	52	2,179.18 165.75 2,013.43 –	912.29 0.91 911.38 –	1,266.89 164.84 1,102.05 –	187.53 5.14 182.39 –	756.75 – 756.75 –
Carpathians	7	149.54 89.48 60.06 –	–	149.54 89.48 60.06 –	143.99 4.15 139.84 –	–
Polish Lowland	32	1,409.61 76.27 1,333.34 –	496.42 0.91 495.51 –	913.19 75.36 837.83 –	0.99 0.99 – –	633.06 – 633.06 –
Carpathian Foreland	13	620.03 – 620.03 –	415.87 – 415.87 –	204.16 – 204.16 –	42.55 – 42.55 –	123.69 – 123.69 –

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

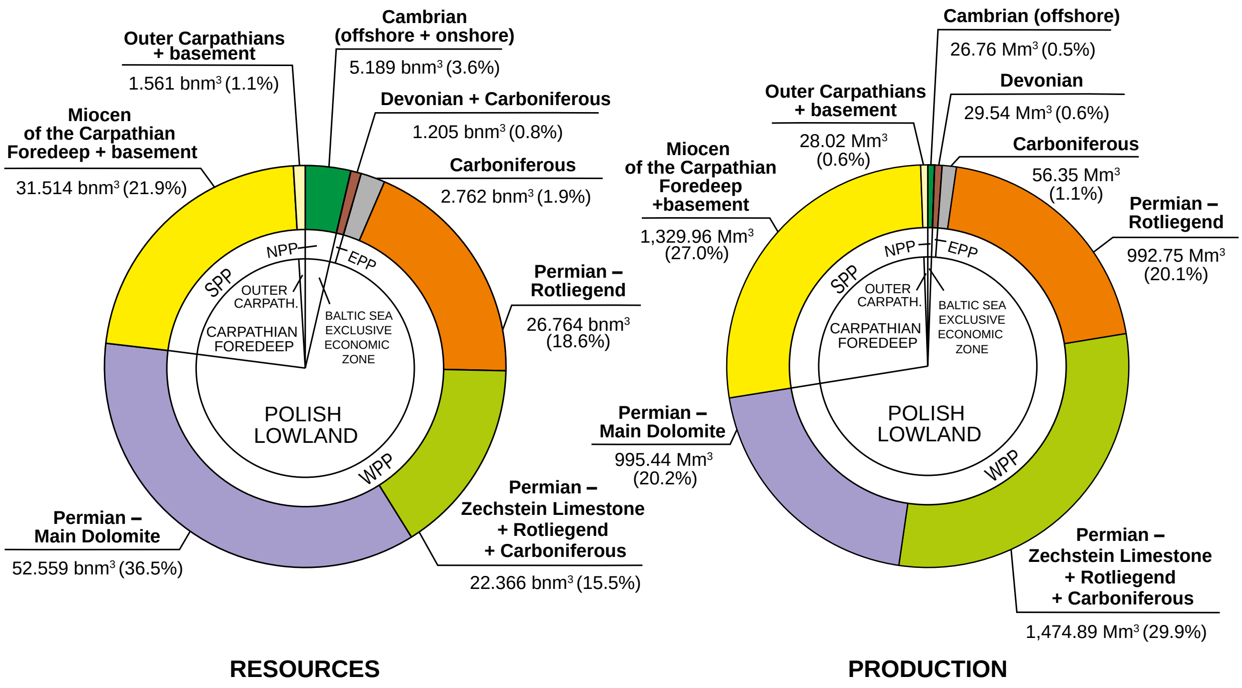


Figure 8.7.2. Structure of exploitable anticipated economic resources and output of natural gas in 2020

NPP – Northern Petroleum Province, **EPP** – Eastern Petroleum Province, **WPP** – Western Petroleum Province, **SPP** – Southern Petroleum Province. According to: own elaboration based on resources and output according to "The balance of mineral resources deposits in Poland as of 12 XII 2020" (in Polish; Szuflicki *et al.*, eds., 2021).

In the Western Petroleum Province (see: Chapter 8.3; Plate 1) natural gas accumulations occur in the Carboniferous and several Permian horizons – Rotliegend, Zechstein Limestone and Main Dolomite. Natural gas occurs within fields of massive- and block-types with a water- or gas-drive exploitation mechanism. In this region only a few gas fields contain high-methane gas, the remaining gas fields contain high-nitrogen natural gas with a content of methane ranging from 30% up to over 80%. Therefore, it is often a nitrogen-methane or methane-nitrogen mixture (fields in which so-called natural gas containing above 90% of nitrogen, are described in Chapter 8.6). Total exploitable resources of natural gas in 148 fields of the Western Petroleum Province amount to 104.451 bnm³ (72.6% of total resources), from which 2.762 bnm³ (1.9%) occur within the Carboniferous fields, 26.764 bnm³ (18.6%) within the Rotliegend fields, and 52.559 bnm³ (36.5%) within the Main Dolomite fields (Fig. 8.7.2). Remaining resources, that is 22.366 bnm³ (15.5% of total resources), have been documented within the Zechstein Limestone and sometimes within the underlying (hydraulically connected) Rotliegend and Carboniferous strata. The Western Petroleum Province of the Polish Lowland has significant exploration potential in its Main Dolomite formation, in which prospective natural gas resources within conventional accumulations are assessed at about 219 bnm³ (Feldman-Olszewska *et al.*, 2020a). Regarding the exploration potential, more important is the Rotliegend seems to be more important. In it conventional accumulations of prospective resources amount to about 1,410 bnm³ (Feldman-Olszewska, *et al.*, 2020a), and a further 345–812 bnm³ constitute the estimated geological resources of tight gas (Wójcicki *et al.*, 2017, 2020). Prospective resources of conventional natural gas connected with the Carboniferous are assessed at about 7.42 bnm³ (Feldman-Olszewska *et al.*, 2020a). The Carboniferous rocks have the highest potential regarding unconventional tight gas accumulations – 1,145 bnm³ (Wójcicki *et al.*, 2017, 2020). Natural gas can also potentially occur within younger Mesozoic strata – Jurassic and Cretaceous, for which probable resources were estimated at about 11.25 bnm³ and hypothetical resources at 55.22 bnm³ (Feldman-Olszewska *et al.*, 2020a). However, natural gas fields have not been documented within such horizons on the Polish Lowland, so far.

In the Northern Petroleum Province (see: Chapter 8.3; Plate 1) conventional natural gas accumulations have been documented within the Cambrian, in 9 fields, however in all 4 onshore fields and in the B 3 and B 8 offshore fields, located in the Baltic Sea, natural gas accompanies crude oil and/or oil condensate. Total exploitable resources of natural gas in the Northern Petroleum Province amount to 5.189 bnm^3 (3.6% of total resources), of which 5.179 bnm^3 are located within offshore fields (Fig. 8.7.2). Prospective resources of conventional natural gas, connected with the Cambrian, are assessed at about 1.3 bnm^3 (Feldman-Olszewska *et al.*, 2020a), whereas estimated geological resources of tight gas amount to 38 bnm^3 (Wójcicki *et al.*, 2017, 2020).

In the Podlasie and Lublin regions, that is within the area of the Eastern Petroleum Province, the total exploitable resources in 5 documented fields amount to 1.205 bnm^3 (0.8% of total resources), of which 1.155 bnm^3 are within the Devonian and the remaining part within the Carboniferous (Fig. 8.7.2). Prospective resources of conventional natural gas located within the Devonian and Carboniferous are assessed at about 38.6 bnm^3 (Feldman-Olszewska *et al.*, 2020a).

The Northern and Eastern Petroleum Provinces, which is a part of the Polish Lowland located on the East European Platform, is also a prospective area for unconventional gas fields within the Lower Paleozoic shales – in the Piaśnica, Sasino, Jantar and Pelplin formations (Wójcicki *et al.,* 2017; Podhalańska *et al.*, 2020a). Assessments of total technical exploitable resources of natural gas within both provinces, calculated using the volumetric method, amounted to 202.0–788.3 bnm^3, whereas 75.3–622.2 bnm^3 are located in the Polish Economic Zone of the Baltic Sea.

Exploitable resources of natural gas in the 1989–2020 period have displayed a declining tendency, with only 3 short episodes of increases (Fig. 8.7.1). In the 1989–2001 period, resources were decreasing on average by about 1.5% annually. Then, in the 2002–2004 period, they increased by 15.7 bnm^3 (that is by 10.2%), mainly due to including newly documented fields into "The balance…" within the area of the Polish Lowland: Brońsko, documented in the Zechstein Limestone and Carboniferous, Międzychód and Lubiatów, documented in the Main Dolomite, the B 4 and B 6 fields, documented in the Cambrian, in the Polish Economic Zone of the Baltic Sea. The decrease in exploitable resources in the 2005–2007 period (by 15.5 bnm^3, that is by 11.2%), resulted mainly from the intensive exploitation and resource verification of the Barnówko-Mostno-Buszewo field (Main Dolomite), and due to a lack of documentation of new fields. Another increase in resources (the 2008–2009 period) was due to better exploration of already documented fields, and the discovery of 16 new fields with their total resources estimated at 3.1 bnm^3. The most significant decrease in resources was recorded as the result of a better resources assessment of the Brońsko field, within the Zechstein Limestone with its Carboniferous basement (8.9 bnm^3), and the Paproć field within the Rotliegend (3.3 bnm^3), located on the Polish Lowland. From 2010 to 2017, average annual total resources were decreasing by about 3%, until their lowest in the last 30 years, that being 116.96 bnm^3 in 2017. In 2018, the new Krobielewko field was documented within the Main Dolomite (25.89 bnm^3) and the Miłosław field within the Rotliegend – both fields located on the Polish Lowland; there were also smaller fields documented – the B 21 within the Carboniferous in the Polish Economic Zone of the Baltic Sea, and the Jata field within the autochthonous Miocene of the Carpathian Foredeep. Moreover, in 2019, the domestic balance had increased as a result of documenting new fields in the Polish Lowland – the Połęcko and Wielichowo W fields within the Main Dolomite, the Czarna Wieś and Pniewy fields within the Rotliegend, and the Brzyska Wola, Olchowiec and Rogoźnica fields documented within the autochthonous Miocene of the Carpathian Foredeep. Moreover, due to better exploration during the course of exploitation, and thanks to a more intensive exploitation process, significant increases in resources were recorded in previously documented fields in the Polish Lowland e.g. the Barnówko-Mostno-Buszewo, Kościan S, Paproć W fields within the Main Dolomite, the Borowo, Młodasko, Paproć and Wilcze fields within Rotliegend and the Mełgiew A and B fields within the Devonian, the B 6 field within the Cambrian in the Polish Economic Zone of the Baltic Sea, and the Pruchnik-Pantalowice and Przemyśl fields within the autochthonous Miocene of the Carpathian Foredeep. As a consequence, the natural gas resources volume significantly increased in a 2-year period reaching 141.97 bnm^3 as of the end of 2019. The only minor decrease in resources was recorded in 2020, as the result of compensated exploitation through documentation of the Gnojnica field (0.15 bnm^3) within the Miocene of the Carpathian Foreland and increasing the resources of the Polish Lowland fields – Brońsko (Zechstein Limestone and its Carboniferous basement, Trzebusz (Carboniferous), Paproć and Załęcze (Rotliegend).

Exploitable resources in 2020 (Tab. 8.7.1) include 7 fields designed for underground natural gas storage facilities: the remaining resources within these fields are treated as cushion gas (buffer capacity) and will not be exploited during a facility existence. Total natural gas resources used as cushion gas and contained within the storage facilities amount to 6.653 bnm^3. Further fields were designated for underground natural gas storage facilities, including: Daszewo (27.72 bnm^3), Bonikowo (328.63 bnm^3) and Wierzchowice (5,728.12 bnm^3) documented on the Polish Lowland within the Main Dolomite, Zechstein Limestone and Rotliegend, respectively, and such fields as: Strachocina (121.50 Mm^3) within the Outer Carpathian flysch, and Brzeźnica II (45.59 Mm^3), Husów (372.88 Mm^3) and Swarzów (28.80 Mm^3), documented within the autochthonous Miocene of the Carpathian Foredeep. In 2012, the Minister of the Environment issued a concession for an underground natural gas storage facility in the Henrykowice E natural gas field (removed from "The balance…" in 2003), located in the Polish Lowland within the Zechstein Limestone and Rotliegend., Rock salt deposits are also used for hydrocarbons storage: currently there are 2 cavernous underground natural gas facilities operating – Moglino II and Kosakowo.

Natural gas output has been fluctuating significantly for the past 30 years – after a rapid breakdown in 1989, exploitation was intensively and almost continuously increasing from 3.453 bnm^3 in 1990, through 4.474 bnm^3 in 2000, up to 5.839 bnm^3 in 2009. The growth in 2009 was the result of more intensive exploitation from the Polish Lowland fields. In 2010, there was a declining trend recorded (on average by about 2% annually), which continues today. In 2016 and in 2020, output from anticipated sub-economic resources accounted for 0.029% and 0.011% of total domestic output, respectively, with an almost-continuous declining trend visible since 2001.

On land, the most important – when considering total output – are fields located on the Polish Lowland, from which, in 2020, 3.549 bnm^3 of natural gas was exploited. It accounts for almost 72% of total production from domestic fields (Fig. 8.7.2). Natural gas was extracted from the Cambrian (26.76 Mm^3), Devonian (29.54 Mm^3), Carboniferous (56.35 Mm^3), Rotliegend (992.75 Mm^3), Zechstein Limestone which its hydraulically connected to the Rotliegend, and the Carboniferous basement (1,474.89 Mm^3) and Main Dolomite (995.44 Mm^3). From the fields located in the Carpathian Foreland – Miocene in the Carpathian Foreland and its Paleozoic-Mesozoic basement – 1,329.96 Mm^3 of natural gas was extracted, which accounts for about 27% of total domestic production. The Carpathians fields (28.02 Mm^3) and the Cambrian fields, located in the Polish Economic Zone of the Baltic Sea (26.76 Mm^3) are of a minor importance, accounting for about 1% of total domestic output.

Natural gas prices are strictly related to oil prices and usually follow their trends. It should be emphasized that there is no one uniform international market and the gas price changes depend on the supply cost to the pipeline networks and sea terminals (the supply and distribution costs can account for 80% of the total costs). Figure 8.7.1 presents changes in natural gas prices (the average German Import Price) in 1989–2020 in Poland. The price varied in the 1989–2002 period in the range of 2–4 USD/MBtu and then started to increase significantly until 2008. A price increase in 2008, which was the result of a global economic crisis and decreasing supply, and then they decreased in 2009 and 2010, due to declining demand for gas. Within the next two years, the average price increased to almost 11 USD/MBtu, which was followed by a significant decline to about 4.93 USD/MBtu in 2016. In 2017 the price rebounded to 5.62 USD/MBtu, as a result of the increasing demand, especially in China (over 15%). 2018 was the second consecutive year with price growing (to 6.66 USD/MBtu), due to an increase in gas consumption, which was most significant in over 30 years. In 2019 the average price fell to just over 5 USD/MBtu, as production growth outpaced consumption by a considerable margin, and thus the amounts of gas in storage rose in most parts of Poland. 2020 was another year where the price of gas fell to its lowest point since 2003 – 4.06 USD/MBtu, due to much lower demand.

8.8. Unconventional hydrocarbon reservoirs

A. Wójcicki, T. Podhalańska

Shale gas, tight gas and oil deposits are classified as unconventional hydrocarbon deposits based on technical, economic and, to a lesser extent, geological criteria. These deposits are more difficult and more expensive to exploit than conventional ones. They are characterized by a lack of spontaneous production of hydrocarbons to the well in quantities justifying their exploitation, which necessitates well yield (production) stimulation while using hydraulic fracturing. Moreover, shale gas and oil deposits may occur over large areas, irrespective of reservoir traps in geological complexes, which may act as both reservoir and source rock.

Poland began to explore unconventional hydrocarbon accumulations and determine their potential resources in shales and sandstones in 2007–2008, when the first shale gas exploration concessions were issued.

The section presents current knowledge on unconventional tight gas, and shale gas and oil resources. The resource values provided are estimates – these are forecasts of resources, i.e., unrisked, undiscovered, undocumented resources. According to the classification used by international petroleum companies (called the Petroleum Resources Management System – PRMS, by the Society of Petroleum Engineers – SPE) they correspond to the category of "undiscovered" resources, which includes unrisked Petroleum Initially in Place (Natural Gas in Place, Crude Oil in Place) resources and the technically unrisked recoverable resources contained therein.

Tight gas. Information on tight gas comes from the most recently published PGI-NRI report (Wójcicki *et al.*, 2014), which analyzed three geological complexes (hydrocarbon systems) from the most prospective and/or relatively best-investigated and identified regions of Poland. Natural Gas in-Place resource estimates were calculated using the volumetric method (Tab. 8.8.1). These are located in the: Permian Rotliegend sandstones in the Poznań-Kalisz zone, Carboniferous sandstones in the Greater Poland-Silesia zone and Cambrian sandstones in the western Baltic Basin.

An estimate of technically recoverable resources can be hypothetically provided, assuming a recovery efficiency (also called a recovery factor) of 5–15% (average 10%) for each of the regions. This gives, on average, values slightly higher than the proven reserves in conventional gas fields in Poland (i.e. 153–200 bnm^3, or c.a. 5.4–7.1 Tcf).

This work has been continued as part of the Polish Geological Survey's projects, however the latest results have not yet been made public.

Shale gas and oil. Information on shale gas and oil comes from the first report made by the PSG in 2012 (PGI-NRI, 2012) and further works (Wójcicki *et al.*, 2017, 2020). The first report was based on geological information from archival wells, including results of laboratory core sample analyses of parameters crucial for shale gas and oil occurrence. The analyses were conducted on the most prospective and relatively best known – from the point of view of current knowledge – Lower Paleozoic shale rocks in the Baltic-Podlasie-Lublin Basin (Tab. 8.8.2). The assessment of shale gas and oil resources in Poland have been continued in projects of

Table 8.8.1. Predictions of Natural Gas in Place resources of tight gas for selected regions of Poland (Wójcicki *et al.*, 2014)

Geological complex	Depth [m b.s.l.]	Most Probable Resources (P50) [bnm^3]
I – Permian sandstones (Rotliegend)	5,500–6,000 or 5,100–6,000	345 or 812
II – Carboniferous sandstones	1,800–3,500	1.145
III – Cambrian sandstones	2,800–3,100	38
TOTAL	–	**1.528–1.995**

Table 8.8.2. Forecasts of technically recoverable resources of hydrocarbons from shales of the Lower Paleozoic in the Baltic-Podlasie-Lublin Basin (PGI-NRI, 2012; Wojcicki *et al.*, 2017)

Area/resources	Natural gas [bnm^3]	Crude oil [Mt]
Onshore Area (2012)	230.5–619.4	166.6
Offshore Area (2012)	115.6–148.4	48.8–101.1
Onshore Area (2017/2018) SCW	65.7– 434.9	37.7–100.4
Offshore Area (2017/2018) SCW	113.5–166.4	69.5–106.5
Onshore Area (2017/2018) vol.	75.3–622.2	15.8–45.4
Offshore Area (2017/2018) vol.	126.7–166.1	73.4–99.2

the PSG, where all available data from 62 new wells and 63 archival wells was used (unpublished report by Wójcicki *et al.*, 2017 – available in National Geological Archive; summary in Wójcicki *et al.*, 2020). Apart from the Lower Paleozoic rocks of the western part of the East European Platform, other areas also seem to be prospective for shale gas and/or oil occurrence, such as: the clayey-silty Miocene rocks in the Carpathian Foredeep, the Miocene menilite shales in the Outer Carpathians, the Zechstein copper-bearing shale and, the Polish Basin shales from the Rhaetian, Lower and Middle Jurassic, and the Upper Jurassic to Lowermost Cretaceous, the Anthracosia and Walchia shales in the Intra-Sudetic Basin, the Upper Carboniferous shales in the Lublin Basin, Lower Carboniferous shales in the Fore-Sudetic Monocline (area of hybrid zones, comprised of shale and sandstone prospective for tight gas), and the Upper Devonian to Lower Carboniferous shales in Western Pomerania.

In the case of the Lower Paleozoic shale rocks in the Baltic-Podlasie-Lublin Basin, the most promising, depending on region, seems to be the Jantar Formation (in the western part of the Baltic Basin and offshore, and the lower Llandovery), the Sasino Formation (also in the western part of the Baltic Basin and offshore; in the Caradoc, locally also the uppermost Llanvirn) and the Piaśnica Formation (mainly offshore; in the Furong, also less frequently in the lowest Tremadocian). Slightly worse reservoir parameters have been noted for the Pelplin Formation shale, especially in the lower, Wenlockian part of the profile, identified in the Lublin region and in the onshore parts of the Baltic Basin (*inter alia*, Poprawa, 2010, 2020; Więcław *et al.*, 2010; Kosakowski *et al.*, 2016; Podhalańska *et al.*, 2016, 2018, 2020a).

Most probable estimates of (unrisked) technically recoverable resources in the Lower Paleozoic rocks are summarized in Table 8.8.2. The first report (PGI-NRI, 2012) was based on the Estimated Ultimate Recovery method developed and used by the USGS, while in subsequent work (Wójcicki *et al.*, 2017, 2020) estimates were based on the Estimated Ultimate Recovery and volumetric methods. The values of estimated ultimate hydrocarbon recovery from the well (i.e. the amount recovered during the well producing life) were adopted based on information from hydrocarbon-bearing sedimentary basins in the USA, characterized by similar geological and reservoir conditions as the Baltic-Podlasie-Lublin Basin, considering the latest available data. The volumetric method was based on available information of parameters used for prospective shale formations: thickness of shale with corresponding total organic carbon (TOC%) and gas content, pore space saturated with oil and/or gas, silica and carbonate content, gas content, sorption capacity and pyrolytic parameter S1, and hypothetical recovery factors (10% for natural gas and 4% for oil and associated gas). Two alternative scenarios were adopted – optimal (for thickness of shale with TOC >2% and gas contents >1.5 m^3/t exceeding 15 m in individual wells) and boundary (thickness of shale with TOC >1.5% and gas contents >0.5 m^3/t exceeding 10 m). Lower boundaries of the resource intervals (Tab. 8.8.2) refer to minimum ranges of prospective shale reservoirs, while upper boundaries represent maximum ranges of these reservoirs.

Due to a lack of shale gas and oil production in Poland, the estimates of (unrisked) technically recoverable resources (based on assumed values of average ultimate hydrocarbon production from a well and the reservoir parameters of the shale formations) are now highly hypothetical.

9. Metallic raw materials

9.1. Arsenic ores

S.Z. Mikulski

Arsenic (As) ore resources are related to the occurrences of As minerals such as loellingite ($FeAs_2$) and arsenopyrite (FeAsS), hosted in hydrothermal veins and in metasomatic intrusion-related ore types in Poland. Arsenic ores have been reported to be present in a major deposit in Złoty Stok and in numerous ore-bearing veins at Czarnów and Miedzianka, near Kamienna Góra, and other sites (Radzimowice, Klecza-Radomice) in the Sudety Mts. (Plate 3). Arsenic ores were exploited from Złoty Stok between the 16th to the 20th centuries. In addition to As, gold (Au) was also extracted from rich ores with As content reaching up to 40%, which doubled as high grade Au ores containing between 10 to 40 g/t Au. After World War II, the Złoty Stok deposit was exploited in the 1954–1960 period and abandoned thereafter due to very limited demand and the high toxicity of arsenic. According to mining records, in total, approximately 16 t of Au were extracted from this deposit. The amount remaining is estimated at 536,500 t of arsenic ores yielding 19,600 t of As and 1,500 kg of Au. Another abandoned arsenic deposit is Czarnów, in which inferred resources were estimated at about 20,500 t of arsenopyrite ores with a mean content of As of approximately 10.15%. Sulfide ores are accompanied by gold, with a maximum content of several grams per tonne.

9.2. Copper and silver ores

A. Malon, M. Tymiński, A. Chmielewski, S. Oszczepalski

Copper ore deposits occur in many countries throughout the world and under various geological conditions. The most important are porphyry copper deposits, followed by sediment-hosted stratabound copper deposits and exhalative-sedimentary deposits (massive pyrite ores). Moreover, there are other igneous copper ores of various types, generally characterized by smaller resources, but locally of a high economic value.

Polish copper and silver prognostic resources are situated in the areas of the Fore-Sudetic Monocline, Żary Pericline and the North Sudetic Trough in the Lower Silesia, Lubuskie as well as Wielkopolskie voivodeships (Plate 3) and they are related to the Zechstein Kupferschiefer formation (sediment-hosted stratiform copper deposits – SSC, Kupferschiefer-type; Oszczepalski, Chmielewski, 2015, Oszczepalski *et al.*, 2016, 2019). Cu-Ag ores in the Lower Zechstein rocks contain not only enormous copper resources but also silver, which makes silver an equivalent component accompanying copper and co-determines the economic value of individual deposit areas. Moreover, silver plays a significant role in the company's profits, where approximately 12% of KGHM Polish Copper S.A. revenues come from the sale of silver. Cu-Ag ore mineralization is concentrated in the Zechstein copper-bearing series encompassing the following lithostratigraphic units: the Weissliegend sandstone (or the Basal Conglomerate), the Basal Limestone (or the Boundary Dolomite), the Kupferschiefer shale, and the Zechstein Limestone. Cu-Ag ore deposits of significant economic importance and these in operation are located in vicinity of Lubin, Polkowice and Głogów, located on the Fore-Sudetic Monocline in the Dolnośląskie voivodeship (Oszczepalski *et al.*, 2019). In 2020, there were 2 new documentations of copper-silver oredeposits approved on the Fore-Sudetic Monocline – Nowa Sól in the Lubuskie voivodeship and Sulmierzyce Północ in the Wielkopolskie voivodeship.

The copper-bearing series comprise 3 separate lithological layers from the bottom to the top: sandstone at the base, limestone or dolomite (locally), clay-marly or dolomitic shale in the middle and dolomitic limestone in the upper part of copper-bearing series. The strongest copper-silver mineralization occurs in gray-black clayey shale which, therefore, is referred to as copper-bearing shale. The major copper minerals in the ore include: chalcocite (Cu_2S), bornite (Cu_5FeS_4) and chalcopyrite ($CuFeS_2$). They are accompanied by other copper minerals (digenite, covellite, tetrahedrite, tennantite), silver (jalpaite, mckinstryite and stromeyerite, as well as native silver and Ag-Hg natural alloys), lead (galena), zinc (sphalerite), cobalt (cobaltite, safflorite, skutterudite, siegenite), nickel (rammelsbergite, gersdorffite, siegenite) and molybdenum (molybdenite, castainkghgite). A common accompanying mineral is pyrite.

Polish copper-silver deposits on the Fore-Sudetic Monocline extend in a 60 km-long and 20 km-wide belt, from Lubin in the south-east to Bytom Odrzański in the north-west, in which copper and silver ores are currently exploited from the Lubin, Polkowice-Sieroszowice and Rudna mines (Oszczepalski *et al.*, 2019). The copper-silver mineralization is fringed to the west by the Rote Fäule zone, which is represented by hematitized Au-Pt-Pd-bearing rocks (Oszczepalski, Rydzewski, 1997).

Total predicted prognostic resources of copper and silver ores in Poland, in stratabound Zechstein-related deposits, to a depth of 2,000 m, assessed as metal content amounted to 10.30 Mt of Cu, prospective resources – 15.67 Mt of Cu, whereas hypothetical resources – 8.76 Mt of Cu (Oszczepalski *et al.*, 2020).

In 2020, anticipated economic resources in the areas of the Fore-Sudetic Monocline and the North Sudetic Trough amounted to 3,025.94 Mt of copper-silver ore yielding 49.94 Mt of metallic copper and 149.83 kt of metallic silver (Tab. 9.2.1). The anticipated economic resources of copper-silver ores in deposits made available by operating mines in the area of the Fore-Sudetic Monocline amounted to 1,590.98 Mt containing 28.99 Mt of copper and 84.32 kt of silver. It accounted for 52.58% of total anticipated economic resources and this share fell by 5.71% in comparison with 2019. Economic resources of exploited deposits amounted to 1,117.17 Mt of ore and decreased by 40.11 Mt (3.47%). The decrease was a result of exploitation and losses. In 2020, copper-silver mining output gave 29,660 kt of copper-silver ores with a copper content of 1.49% and a silver content of 47.98 g/t, yielding 442 kt of metallic copper and 1,423 t of metallic silver.

Table 9.2.1. Copper and silver ores resources

ore [Mt]
copper [Mt]
silver [kt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**15**	**3,025.94** ***49.94*** ***149.83***	**653.48** ***12.00*** ***37.50***	**1,101.63** ***19.53*** ***58.66***	**1,070.20** ***15.40*** ***45.21***	**200.62** ***3.02*** ***8.46***	**830.17** ***13.32*** ***41.82***	**1,117.17** ***22.31*** ***67.16***
Including resources of exploited deposits								
Deposits of operating mines	6	1,590.98 *28.99* *84.32*	651.23 *11.96* *37.39*	922.27 *16.89* *46.57*	17.48 *0.14* *0.36*	–	1.04 *0.01* *0.04*	1,117.17 *22.31* *67.16*
Including resources of non-exploited deposits								
TOTAL	5	1,411.19 *20.70* *64.42*	–	165.62 *2.48* *11.44*	1,044.96 *15.20* *44.52*	200.62 *3.02* *8.46*	811.05 *13.18* *41.10*	–
1. Deposits covered by detailed exploration	4	218.85 *3.41* *15.35*	–	165.62 *2.48* *11.44*	49.30 *0.89* *3.73*	3.93 *0.04* *0.17*	782.18 *12.96* *41.10*	–
2. Deposits covered by preliminary exploration	1	1,192.34 *17.29* *49.08*	–	–	995.65 *14.31* *40.79*	196.69 *2.98* *8.29*	28.87 *0.22*	–
Including abandoned deposits								
Abandoned deposits	2	23.77 *0.26* *1.08*	2.25 *0.04* *0.11*	13.74 *0.16* *0.66*	7.77 *0.06* *0.32*	–	18.08 *0.13* *0.68*	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

Anticipated economic resources of non-exploited copper-silver ore deposits occur mainly at a depth within the range of 1,000 and 1,250 m, sometimes even to 1,450 m (until now considered as anticipated sub-economic due to their depth parameter). However, during the process of the Nowa Sól and Sulmierzyce Północ deposits documentation, the criteria for parameter threshold values defining a sediment-hosted stratabound copper-silver deposit differed from the ones included in the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987) i.a.: the maximum depth of the deposit bottom was increased. Finally, the depth for Nowa Sól deposit was equal 2,160 m (the average 1,975 m) and for Sulmierzyce Północ it was 2,060 m (the average 1,825 m).

Figures 9.2.1–9.2.3 show resources and output of copper and silver ores and changes in resources and output of metallic Cu and metallic Ag in Poland in the 1989–2020 period. There are also prices of metallic Cu and metallic Ag presented (Fig. 9.2.2 and 9.2.3).

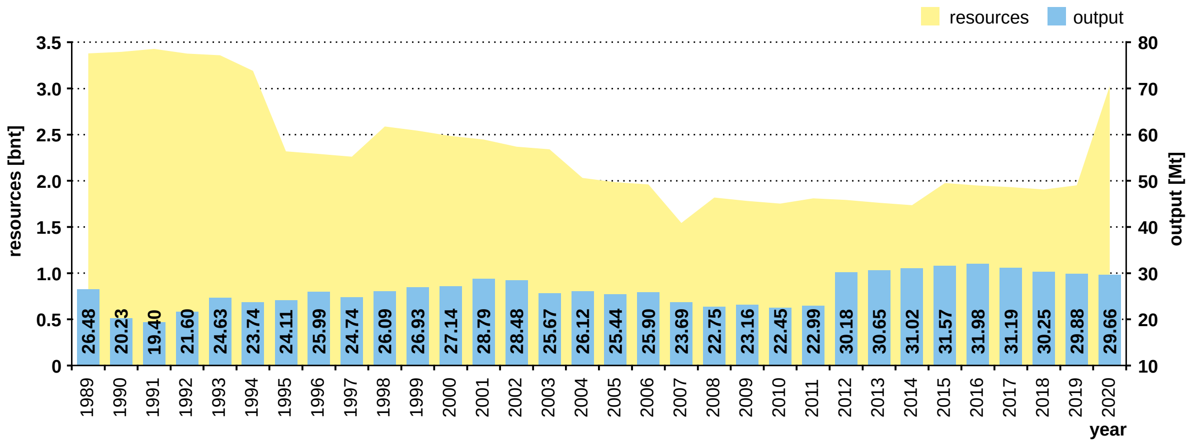


Figure 9.2.1. Copper and silver ores anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

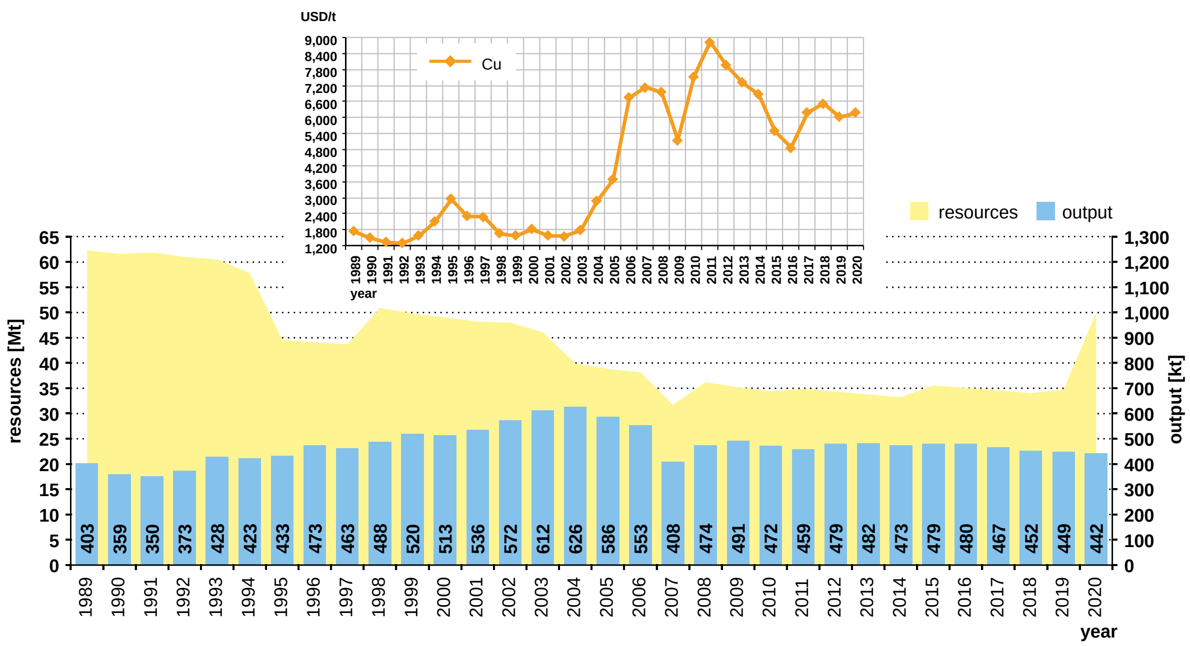


Figure 9.2.2. Metallic copper anticipated economic resources, output and annual prices in 1989–2020 (LME)

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to World Metal Statistics Yearbook

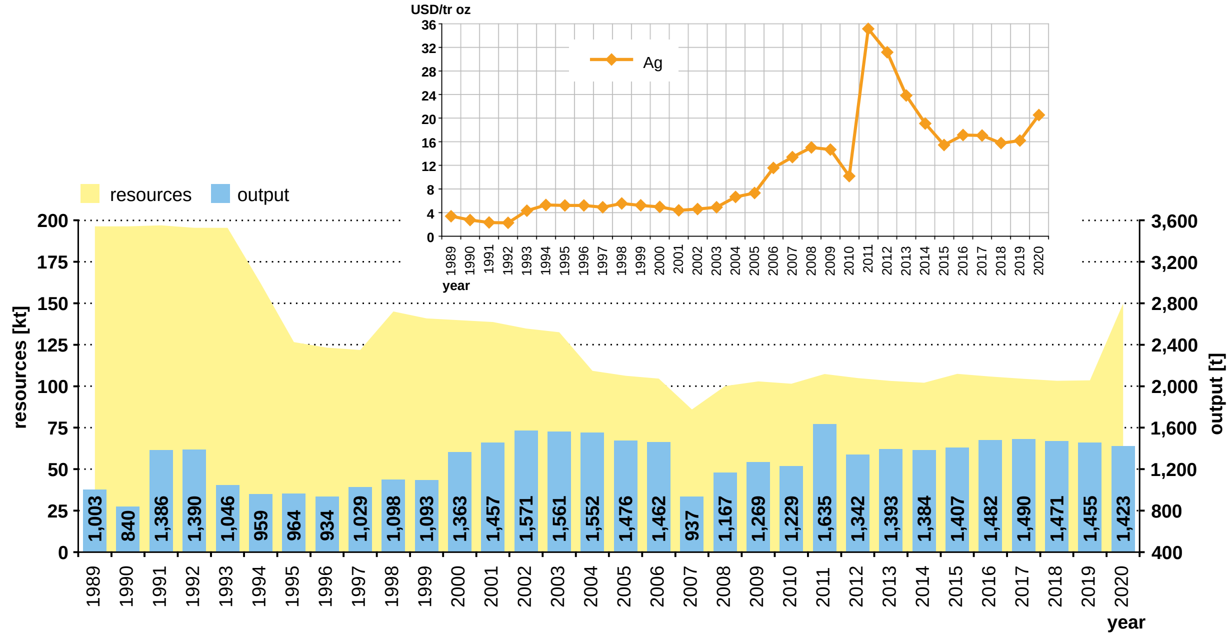


Figure 9.2.3. Metallic silver anticipated economic resources, output and annual prices in 1989–2020 (LME)

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to World Metal Statistics Yearbook

The tendencies for changes in Cu-Ag ores and metals (copper and silver) resources are very similar. Anticipated economic resources of copper and silver ores fluctuated in the presented period (1989–2020). The resources were generally decreasing from 3.38 to 1.74 bnt in the 1989–2014 period and then an increasing tendency was being recorded until 2020 (3.03 bnt). The decreases were connected mainly with changes of criteria for evaluating anticipated ongoing economic resources, with the exception of deposits from the national register and with exploitation. Copper-silver ore resources occurring below a depth of 1,250 m were excluded from the Polish mineral resources balance in 1994 and 1995. It was a significant decrease – the resources decreased by about 30% within a 2-year period. The resources decrease in 2007 resulted from a different attitude in presenting resources data – only in this particular year – without taking into account the so-called "protective pillars" and not considering the real raw material depletion. A significant increase was recorded in 1998, when a new copper-silver ore deposit (Głogów Głęboki-Przemysłowy) was documented. Anticipated economic resources of copper and silver ores decreased in the 2012–2014 period, due to exploitation and increased again in 2015 by 239.16 Mt, as a result of documentation of a new deposit – Radwanice-Gaworzyce (replacing the earlier documented deposits: Gaworzyce, Radwanice-Wschód, Radwanice-Zachód). Over the next 3 years, anticipated economic resources decreased to 1,906 Mt (by 70 Mt) due to exploitation and losses. In 2019, the resources grew by 46 Mt (2.39%), as a result of a new deposit being documented (Żary). The second consecutive resources increase took place in 2020 and it was a significant rise – by 1,075 Mt (55.08%). It was due to the approval of 2 new deposits documentations: Nowa Sól (+848.48 Mt of ore in a C_2 category) and Sulmierzyce Północ (+267.17 Mt of ore: 147.17 Mt in a C_2 category and 120 Mt in a D category).

Prices of copper increased significantly in the 2004–2007 period, and then in the 2010–2011 period, reaching nearly 9,000 USD/t (Fig. 9.2.2). That was the result of a supply shortage, investment fund activity and high import demand from China. The rapid price decrease in the 2012–2016 period was caused by declining demand from the Chinese market, high prices of international stocks, the policy of the United States Central Bank and pull-out of investors from commodity markets. Positive Chinese import data together with an emerging global supply deficit and signs that future technologies would cause a huge demand increase, were the reasons for a price increase in 2017 – the average price increased to 6,163 USD/t.

Another price increase was recorded in 2018 – by 5.87% (to 6,252 USD/t). In 2019, the price of copper slightly decreased, mainly due to rising trade tensions between

China and the United States. The declining tendency was stopped in 2020 when the average copper price amounted to 6,169 USD/t. Main factors for this change were as follows: negative impact on demand from the COVID-19 recession; interruptions to international trade flows in scrap; mine production disruptions in the Americas caused by infections and new workforce safety protocols; strong resurgence in Chinese cathode buying for scrap replacement, improving consumption, restocking and stockpiling purposes.

Silver prices increased systematically in the period from 2002 to 2011, due to growing demand in an electronic industry sector, declining national reserves and increasing investment demand (Fig. 9.2.3). A reduced supply of investment and maintaining industrial demand, were the main reasons for the price decrease in the 2012–2015 period – to 15.45 USD/tr oz. In 2016, the annual average price increased to 17.14 USD/tr oz due to growing demand, whereas in 2017 it fell to 17.05 USD/tr oz as a result of declining demand in spite of decreasing supply. The average annual silver price in 2018 reached 15.78 USD/tr oz (a decrease by 7.45% in comparison with 2017), mainly as a result of a trade dispute between China and the United States, which delivered strength to the dollar, as well as dragging down metal prices, including silver. 2019 brought another increase of prices – to 16.20 USD/tr oz – as global silver demand edged 0.4% higher despite an ongoing global trade war affecting many industries, while silver mine supply declined for the fourth consecutive year, falling by 1.30%. The last year (2020) was characterized by an annual silver prices increase – by 4.31 USD/tr oz (26.60%). Silver prices benefited from the impact of the COVID-19 crisis on investor sentiment – the aftermath of the pandemic's spread across Europe and North America initially drove silver prices sharply down. Nevertheless, later in the year, the silver price gained rapid momentum rallying to a peak of nearly 30 USD/tr oz in August.

Output of copper and silver ores, as well as of metallic copper and silver fluctuated in the period of 1989–2020. Generally, the output of ores was systematically increasing in the period of 1992–2001 to the level of 28.79 Mt in 2001. Thereafter, a decreasing tendency was visible and during the next 9 years the exploitation amount decreased by 6.34 Mt (22.02%) to 22.45 Mt in 2010. The most significant output increase happened in 2012, when it grew by about 30% (7.19 Mt) compared to the previous year – mainly as a result of more intensive exploitation from the Sieroszowice deposit. In the next 4 years the output increased slightly to 31.98 Mt of ore in 2016. The output of metallic copper was regularly increasing in 1992–2004 – to 626 kt. The next 4 years brought an output decrease to 474 kt in 2008. The size of output amounted to 408 kt in 2007, was a result of a different approach to data presentation – also applying to metallic silver. Within the next 8 years the size of output remained within the range of 459–491 kt annually. Regarding metallic silver, substantial fluctuations took place in the 1989–1996 period and then resources were increasing until 2002 (to 1,571 t). Thereafter, a 6-year period of decreases was recorded (except for 2007) and the silver output amounted to the lowest amount since 1999. Until 2011 the size of exploitation increased by 40%, to the highest point in the whole presented period – mainly due to increases noted for the Sieroszowice deposit in 2011. After the evident decrease in 2011 it did not changed for the next 6 years, but slightly increased to 1,490 t in 2017. The last 3–4 years (2017–2020, 2018–2020 for silver) brought a systematic output decrease, regarding both the ores and the metals. In 2017, the magnitude of exploitation of ores decreased by 799 kt (2.50%) with metallic copper output decreasing by 13 kt (2.71%) and silver output increasing slightly – by 8 t (0.54%). That was due to ore exploitation decreases from 4 out of 6 exploited deposits, especially from Rudna and Polkowice. Another exploitation decline was registered in 2018 – by 933 kt (2.99%) of ore, 15 kt (3.21%) of copper and 19 t (1.28%) of silver – resulting from output decreases mainly from the Głogów Głęboki-Przemysłowy, Rudna and Sieroszowice deposits. In the last 2 years, output drops were much smaller and amounted to 371 kt of ore in 2019 and 221 kt in 2020. Both metals also decreased in exploitation – copper by 3 kt and 7 kt, silver by 16 t and 32 t, respectively. The significant output volume declines were noted for the Rudna, Polkowice and Lubin-Małomice deposits in 2019 and for the Rudna and Polkowice deposits in 2020.

From the domestic copper-silver ores there are also obtained such associated elements as: Au, Ni, Pb, Se, Re, as well as sulfuric acid being manufactured as a by-product.

In 2020, the KGHM Polish Copper S.A. metallurgical production gave 560.4 kt of electrolytic copper, including 413.3 kt of their own concentrates and 147.0 kt of imported ones. Moreover, there was 3,011 kg of gold – both from their own and imported concentrates – produced.

As mentioned above, the most important product beside metallic Cu, when considering economic value, is silver recovery. According to information provided by KGHM Polish Copper S.A., in 2020, on the copper-silver ores exploited in Poland, there were 1,323 t of Ag, 878 kg of Au, 28.79 kt of Pb, 2.06 kt of $NiSO_4$, 73.80 t of Se and 9.51 t of Re metallurgically produced.

9.3. Gold

S.Z. Mikulski

Gold occurring in various geological formations in Poland was a subject of mining activity from at least the early Middle Ages. At present, gold is extracted only from copper-silver ore deposits located in the area of the Fore-Sudetic Monocline. Gold occurs mainly in the oxidized facies sediments (named from German Rote Fäule), mainly in rocks of the Weissliegend Sandstone, the Rotliegend and in the lower parts of the Zechstein copper-bearing schists (Kupferschiefer). Gold is recovered in the course of technological processing of sulfide ore and imported inputs. The gold recovery from domestic deposits has been generally stable at about 400 kg per year in the 2012–2015 period, and only in 2014 it amounted to 226 kg. In 2015, 431 kg of gold were recovered from domestic sulfide Cu-Ag ore and 2,703 kg of gold (taking into account imported inputs). In the next 5 years the amount of gold recovered from domestic sulfide Cu-Ag ore varied, but has been increasing in general – from 402 kg in 2016 to 572 kg in 2017, through a dip in 2018 to 523 kg, and followed by significant increases in 2019 (674 kg) and in 2020 (878 kg) – to the highest level in the analyzed period. Taking into account the imported inputs, there were consecutive amounts obtained: in 2016 – 3,539 kg of gold, platinum and palladium; in 2017 – 3,648 kg of gold, platinum and palladium; in 2018 – 2,587 kg of gold, platinum and palladium; in 2019 – 3,225 kg of gold; and in 2020 – 3,011 kg of gold.

The gold and arsenic mine in Złoty Stok, closed in 1960, was the biggest active gold mine in the Sudety Mts. (Plate 3). Documented in 1954, gold resources of the Złoty Stok deposit were estimated at 2,000 kg in ore anticipated economic resources and 490 kg in ore anticipated sub-economic ones. The mean content of gold in the loellingite-arsenopyrite ore is 2.8 g/t. This deposit was exploited in the 1954–1960 period. During that period about 25% of documented resources were exploited and the deposit was abandoned because of very limited demand and high toxicity of arsenic. At present, the chances for reactivating this mining operation are miniscule. Gold was also extracted from hydrothermal gold-bearing quartz-sulfide veins at Radzimowice, Klecza-Radomice, Czarnów and Wądroże Wielkie. Also placer gold was subject of extraction from the Cenozoic sand and gravel, located in the Dolnośląskie voivodeship. The gold-bearing sediments occurred in numerous river valleys (e.g. Bóbr, Kwisa, Kaczawa, Nysa Łużycka) in the vicinities of Złotoryja, Lwówek Śląski and Bolesławiec.

Prospective resources of gold in Poland are assessed at 419.2–431.8 t, whereas prognostic resources at 34.3 t (Mikulski, Oszczepalski, 2020).

In 2020, the geological documentation of a small deposit of gold ore in kaolin clays was approved – Mikołajowice in Dolnośląskie voivodeship. The deposit contains anticipated economic resources in a C_1 category documented at 5,028.7 kt of ore, 968.0 kg of metallic gold and 723.8 kt of kaolinite; anticipated sub-economic resources also documented in a C_1 category amount to 4,842.6 kt of ore, 69.7 kg of metallic gold and 435.8 kt of kaolinite. The deposit is formed by one bed of kaolin weathering loams with quartzitic debris – the result of quartz-micaceous schists and quartz-feldspar vein weathering processes. The average content of gold in the anticipated economic ore was geochemically determined at 172.4 ppb, whereas in anticipated sub-economic ore at 14.4 ppb.

9.4. Iron, titanium and vanadium ores

S.Z. Mikulski

In Poland, iron ores were exploited from the 1950s to the 1970s, in several mines situated in the areas around Częstochowa, Kielce and Łęczyca. The Fe-ore is hosted in sedimentary rocks in the form of accumulations of siderite nodules and iron-bearing limonitic sand. Resources of iron ore were removed from the registry of Polish mineral raw material deposits by a decision of the Minister of the Environmental Protection, Natural Resources and Forestry in 1994, as failing to meet economic criteria. Since then, there has been no economic iron deposit documented in Poland.

Deposits of vanadium-bearing magnetite-ilmenite ores occur in anorthosite complexes of the Mesoproterozoic Suwałki Anortosite Massif (in north-eastern Poland) at depths from 850 to 2,300 m. Deposits were discoverd as a result of intense drilling exploration and an appraisal drilling program launched in the 1970s. In order to classify ore resources, special economic criteria were elaborated and accepted in 1996. On the basis of these new criteria, ore resources of the Krzemianka and the Udryn deposits were classified as sub-economic due to a low content of metals, especially of vanadium (0.26–0.31% V_2O_5 on the average) and their occurrence at great depth.

At present, magnetite-ilmenite ore appears to be of interest mainly as a raw material for vanadium and titanium. According to an evaluation by Nieć (2003), the cut-off grade equivalent of V_2O_5 in economic ore should reach 0.73%, thus constituting only 1% of documented resources. However, large resources of shallow-seated or even exposed deposits of this type were recently discovered and proven in South Africa and several other places throughout the world. This renders any attempt to develop ore deposits of the Suwałki area difficult to exploit in the foreseeable future. Their classification as sub-economic deposits is overly optimistic in the present conditions. Moreover, any decision to start the development of the Suwałki ore deposits would bring a very high risk of social and environmental conflict. It should be noted that in the Fe-Ti-V oxide deposits in NE Poland, cobalt is present in the sulfide ores that accompany magnetite-ilmenite mineralization and has been identified by PGI-NRI. The roughly estimated resources of cobalt in that area are approximately 150 kt (Mikulski *et al.*, 2018).

A bog iron ore deposit in the Dębe Małe area is relatively small, with resources estimated at 8,000 t. Its resources appear to lack utility as a raw material for the steel industry, but can easily find other industrial uses, especially as an adsorbent of H_2S, CO_2 and organic compounds of sulfur in cleaning combustion flue gasses, as well as in other environmental activities.

9.5. Metals and elements coexisting in ores and other raw materials

S.Z. Mikulski

A group of mineral raw materials described in this chapter comprises different metals, which are co-occurring elements mainly in sulfide ores deposits. This is the case for Polish copper-silver and zinc-lead ores deposits with fairly large records of various co-occurring elements. Elements – which often have a high market value – are already being recovered or may become recoverable during processing of given ores. Accumulations of some of these elements were covered by prospecting and exploration that often resulted in evaluations of their indicated/inferred resources. On occasion, their resources are documented.

Rare-earth elements and other valuable dispersed elements were also found in: beach sand of the Ławica Słupska deposit (estimated resources: zirconium – 2 kt of $ZrSiO_4$, titanium – 12 kt of TiO_2) and the Ławica Odrzana deposit (geological resources approved in 2014: zirconium – 25.28 kt of $ZrSiO_4$, titanium – 156.78 kt of $FeTiO_3$ – ilmenite, 20.23 kt of TiO_2), potassium-magnesium salts (boron – 6 kt, bromine – 7.2 kt) and saline water and brine (32.14 Mm^3 of brine in the Łapczyca deposit). Data on boron, bromine, zirconium and titanium (with the exception of the Ławica Odrzana area) come from evaluations made in the 1960s and no new calculations have been made since then.

Table 9.5.1 shows a summary of estimations of the resources of major co-occurring elements as of the end of 2020.

Table 9.5.1. Elements co-occurring in ores and other mineral raw materials [kt]

Elements	Copper-silver ores	Zinc and lead ores	Ni ores	Fe-Ti-V oxides	Total
Arsenic (As)	–	5.57	–	–	5.57
Gallium (Ga)	–	0.13	–	–	0.13
Germanium (Ge)	–	0.03	–	–	0.03
Cadmium (Cd)	–	20.21	–	–	20.21
Cobalt (Co)	156.98	–	>10.00	>150.00	>316.98
Molybdenum (Mo)	112.95	–	–	–	112.95
Nickel (Ni)	102.45	–	–	–	102.45
Rare-earth elements (REE)	30.99	–	–	–	30.99
Rhenium (Re)	0.56	–	–	–	0.56
Sulfur (S)	5,137.08	1,956.35	–	–	7,093.43
Silver (Ag)	149.83	0.80	–	–	150.63
Thallium (Tl)	–	0.15	–	–	0.15
Vanadium (V)	211.87	–	–	–	211.87

9.6. Molybdenum-tungsten-copper ores

S.Z. Mikulski

The Myszków deposit containing molybdenum-tungsten ores with accompanying copper is situated at the north-eastern margin of the USCB (Plate 3), in the contact zone of the Małopolska Block and the Upper Silesian Block, separated by the Hamburg-Cracow Tectonic Zone. The deposit is a Mo-W-Cu porphyry type. Its stockwork-type ore mineralization forms a system of quartz veins with ore minerals, sulfides and oxides related to igneous activity in the Variscan. An intensive drilling program carried out by PGI in 1975–1992 made the detailed exploration of Myszków deposit possible in an area of 0.5 km^2, down to a depth of 1,300 m. Exploration conducted in 1993 allowed the estimation of the Myszków deposit inferred resources in the C_2 resources category (documentation prepared by PGI). Anticipated economic resources of ore, at a depth down to 1,000 m, were estimated at about 380 Mt, with 0.23 Mt of Mo, 0.18 Mt of W and 0.55 Mt of Cu, and a mean contents of Mo and W calculated were 0.049% and 0.041%, respectively.

In 2007, anticipated economic resources of the Myszków deposit were re-evaluated to find that they are markedly larger than previously estimated, exceeding 551 Mt of Mo-W-Cu ore and anticipated sub-economic resources were estimated at 750 Mt of Mo-W-Cu ores. Anticipated economic resources of this deposit were estimated at about 0.295 Mt of Mo, 0.238 Mt of W and 0.804 Mt of Cu, and anticipated sub-economic resources – at 0.298 Mt of Mo, 0.212 Mt of W and 0.771 Mt of Cu. The Myszków ore mineralization has not yet begun to be exploited. According to available data, there are high chances for the discovery of other deposits of Mo-Cu porphyry ores with tungsten in the contact zone of the Małopolska Block and the Upper Silesian Block along the Cracow-Lubliniec Fault Zone.

Molybdenum co-occurs with other metals in porphyry-type ore mentioned above, as well as in the stratabound copper-silver deposits of the Fore-Sudetic Monocline and hard coal deposits in the USCB. However, nowadays, applied technological processes have yet to focus on finding a way to separate molybdenum effectively.

Numerous occurrences of Mo-W mineralization have been found in zones of the Late Carboniferous granitoid intrusions in the Sudety Mts., but no concentrations of economic importance were found thus far in this area. Molybdenum forms different genetic types of deposits, which usually occur separately. The most important are the porphyry type deposits (Mo-, and Cu-Mo-subtypes), while skarns, greisens and hydrothermal veins, as well as Mo-bearing black shales, are all less important in terms of deposit potential (Mikulski *et al.*, 2012).

9.7. Nickel ores

S.Z. Mikulski

Nickel ore deposits occur in the Dolnośląskie voivodeship (Plate 3). These are saprolite (weathering) type, siliceous nickel ore deposits, related to the Paleozoic serpentinized ultramafic rocks (peridotite). Exploitation of the major nickel ore deposit in Szklary, in the vicinity of Ząbkowice Śląskie, was phased out in 1983 due to being deemed uneconomic. Anticipated economic resources of nickel ores increased significantly in 2014 due to the documentation of a new deposit – Szklary 1. This deposit was allocated from the Szklary-Szklana Góra deposit. Therefore, the anticipated economic resources (in B and C_1 categories) amounted to 17.21 Mt of ores and with metallic nickel content of 125.0 kt (limiting content of Ni in the deposit is 0.8%). Since then the anticipated economic resources of nickel ores have not changed (Tab. 9.7.1). Anticipated sub-economic resources amount to 21.32 Mt of ore and 84 kt of metallic nickel. The ore resources of the Grochów deposit were classified only as anticipated sub-economic.

Prognostic resources of the Ni-layer silicate-type of ore, occurring in small and separate lenses in Cenozoic rocks (weathering product of serpentinites) in the northern, eastern and southern Cenozic cover of the Sowie Mts. block gneisses (Lower Silesia), are estimated for about 25 kt (Mikulski, Sadłowska, 2020). In the abandoned Ni-saprolite type Szklary deposit, cobalt resources were also identified and estimated at >10 kt with an average contents of approximately 219 ppm Co (Mikulski *et al.*, 2018).

Except for the weathering type, nickel is also the co-occurring metal in copper-silver ores of the Zechstein Kupferschiefer formation located in the Fore-Sudetic Monocline (at about 102.45 kt as of the end of 2020). Nickel is recovered in technological processes as nickel sulfate. In 2015, the processing of copper-silver ores gave 2,967 t of nickel sulfate. In the last 5 years the size of nickel sulfate-output was as follows: in 2016 2,743 t of nickel sulfate; in 2017 – 1,790 t; in 2018 – 1,732 t; in 2019 – 1,993 t; and in 2020 the processing of copper-silverores gave 2,058 t of nickel sulfate.

Table 9.7.1. Nickel ores resources [Mt]

ore
metallic nickel

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	5	**17.21** ***0.13***	**6.53** ***0.06***	**10.68** ***0.07***	–	–	**21.32** ***0.08***	–
Including resources of non-exploited deposits								
TOTAL	2	4.37 *0.02*	–	4.37 *0.02*	–	–	13.88 *0.05*	–
1. Deposits covered by detailed exploration	1	4.37 *0.02*	–	4.37 *0.02*	–	–	–	–
2. Deposits covered by preliminary exploration	1	–	–	–	–	–	13.88 *0.05*	–
Including abandoned deposits								
Abandoned deposits	3	12.84 *0.10*	6.53 *0.06*	6.31 *0.04*	–	–	7.44 *0.03*	–

9.8. Tin ores

S.Z. Mikulski

Tin is used for production of a wide variety of valuable alloys, most commonly used to make copper-tin alloys. The metal is also used for coating steel and other metals, to prevent corrosion. Tin-plated steel cans and containers are widely used for food preservation, but that application has become less prevalent due to a growing replacement of tin with other materials.

Tin is mainly extracted from its basic compound, usually cassiterite (SnO_2), occurring in a form of primary or secondary accumulations.

In Poland, tin ore occurs in 2 deposits: Gierczyn and Krobica, both located in the Stara Kamienica Lower Paleozoic Schist Belt in the Sudety Mts. (Plate 3). These deposits of tin were classified as anticipated sub-economic and were estimated at 5.5 Mt of ore, with an average Sn content of about 0.5%. Prospective tin ore resources in the whole area of the Stara Kamienica Schist Belt are estimated at about 20 Mt, with a content of metallic tin of about 100 kt (Mikulski, Małek, 2020). Geochemical investigation carried out by PGI-NRI of Sn deposits revealed that the cassiterite-sulfide ores may contain elevated concentrations of critical elements, such as Co, In, Bi and Pt.

9.9. Zinc and lead ores

A. Malon, S.Z. Mikulski, M. Tymiński

Documented zinc and lead ore deposits occur in an area of the northern and north-eastern margin of the USCB in southern Poland. The Zn-Pb ore deposits occurring in that area are related mainly to carbonate rock formations of the Silesian-Cracow region built of Permian-Mesozoic successions resting monoclinally on Paleozoic sedimentary deposits. The rock-hosting Zn-Pb mineralization ranges in age from the Devonian to Jurassic. Resources of economic importance are mainly related to ore accumulations in the so-called Ore-bearing Dolomites of the Muschelkalk (Middle Triassic). The zinc-lead ores occur in the form of pseudo-layers, sub-horizontal lenses and nest-like replacements. The Silesian-Cracow region is regarded as the world's largest area of Zn-Pb ore deposit occurrences of the so-called Mississippi Valley-type (MVT), although mining from these deposits ceased in 2021, there are still large resources of Zn-Pb sulfide ores in undeveloped deposits in the Zawiercie area.

There are 4 areas of Zn-Pb ore deposits identified in the Silesian-Cracow region: Chrzanów, Olkusz, Bytom and Zawiercie (Plate 3). In 2020, exploitation was carried out from the Klucze I, Olkusz and Pomorzany deposits in the Olkusz region. The Zn-Pb ore deposits of the areas around Bytom and Chrzanów are of historical and scientific importance only. The deposits exhausted as a result of continuous exploitation since the Middle Ages and now comprise some anticipated sub-economic accumulations, mainly of oxide ore with minor participation of sulfide ore. The exploitation of deposits of the fourth region (Zawiercie) has not yet been commenced.

The Zn-Pb concentrations accompanying the copper-silver ores occur in the Zechstein copper-silverdeposits in the Fore-Sudetic Monocline. The average lead content falls in the range of 0.05–0.3%, therefore lead recovery is possible only in the course of treating copper concentrate in smelters. According to the data provided by KGHM Polish Copper S.A., in 2020 copper processing was accompanied by the recovery of 28.79 kt of lead.

The most important prospects for the Zn-Pb ore resources increases are connected with the Silesian-Cracow region – where in the Middle Triassic and Devonian carbonate rocks Zn-Pb sulfide mineralization of the MVT type occurs. As of the end of 2018, in the Olkusz region, the estimated prognostic resources amounted to about 35 Mt of Zn-Pb ores, whereas in the Zawiercie region – about 25 Mt of Zn-Pb ores (Mikulski, Retman, 2020). The Zn-oxide ore (calamine), occurring in the Silesian-Cracow region has not been exploited for many years and its prognostic resources in abandoned deposits have to be verified and assessed according to the current parameter limits that define a deposit and its boundaries.

Estimations of Zn-Pb ore resources in the Silesian-Cracow region have been changing markedly over the last 50 years. These changes resulted, on one hand, from intensive exploration and exploitation of deposits, and on the other, from removing resources of zinc oxide ore (calamine) from the official records of domestic resources of mineral raw materials. The decision to remove the resources was connected with high occupational and environmental hazards, associated with a technology used at that time for oxide ore processing. The technological problems were finally solved, therefore it appeared necessary to introduce special criteria for classification of oxide ore resources not meeting criteria for sulfide ores. Such separate criteria for Zn oxide ore resources were established by means of the "Regulation by the Minister of the Environment amending regulation on the classification of mineral reserves and resources" (dated the 9th of January, 2007 – Journal of Laws of 2007, Item 57). According to the GML effective as of the 1st of January, 2012, there are separate criteria for sulfide and oxide ore deposits called "parameter limits that define a deposit and its boundaries".

Anticipated economic resources of Zn-Pb ores as of the end of 2020 amounted to 90.98 Mt of ore yielding 3.85 Mt of zinc and 1.43 Mt of lead (Tab. 9.9.1). The majority of these resources are documented in the C_2 category (52.69%) and the C_1 category (25.73%), with fewer resources in the A+B categories (13.62%) and the D category (7.95%). Anticipated economic resources within the exploited deposits account for 15.21% of total sulfide ore resources. The economic resources of exploited deposits amounted to 2.05 Mt of ore containing 0.08 Mt of zinc and 0.04 Mt of lead. The resources decreased by 1.71 Mt (45.48%) in comparison with 2019, due to exploitation and losses. In 2020, Polish mines extracted 1,435 kt of ore yielding 43 kt of zinc and 18 kt of lead. It should be emphasized that these deposits also contain

Table 9.9.1. Zinc and lead ores resources [Mt]

ore
metallic zinc
metallic lead

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**21**	**90.98** ***3.85*** ***1.43***	**12.39** ***0.47*** ***0.18***	**23.41** ***1.07*** ***0.44***	**47.94** ***2.10*** ***0.70***	**7.23** ***0.21*** ***0.11***	**55.91** ***2.00*** ***0.63***	**2.05** ***0.08*** ***0.04***
Including resources of exploited deposits								
Deposits of operating mines	3	13.84 *0.53* *0.20*	12.39 *0.47* *0.18*	1.44 *0.06* *0.02*	–	–	5.67 *0.21* *0.12*	2.05 *0.08* *0.04*
Including resources of non-exploited deposits								
TOTAL	14	77.14 *3.32* *1.23*	–	21.97 *1.01* *0.42*	47.94 *2.10* *0.70*	7.23 *0.21* *0.11*	9.43 *0.41* *0.15*	–
1. Deposits covered by detailed exploration	7	70.84 *3.06* *1.10*	–	21.97 *1.01* *0.42*	43.91 *1.93* *0.66*	4.96 *0.12* *0.03*	6.74 *0.29* *0.12*	–
2. Deposits covered by preliminary exploration	7	6.30 *0.26* *0.13*	–	–	4.03 *0.17* *0.05*	2.27 *0.10* *0.08*	2.69 *0.12* *0.03*	–
Including abandoned deposits								
Abandoned deposits	4	–	–	–	–	–	40.80 *1.39* *0.36*	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

elements accompanying Zn-Pb ores, such as S, Cd, Ag, Ga, As, and Tl, which could be of interest to the industry (Mikulski *et al.*, 2020).

The Figures 9.9.1–9.9.3 show resources and output of Zn and Pb ores and changes in resources and output of metallic zinc and metallic lead, in Poland, in the 1989–2020 period.

Anticipated economic resources of Zn-Pb ores were significantly decreasing in the 1989–2013 period from 343 Mt to about 74 Mt – the lowest point in the whole presented period (Fig. 9.9.1). It was mainly due to criteria changes for estimating anticipated economic resources, and due to the exclusion of some resources from the Polish mineral resources balance (years: 1991, 1992, 2007, 2008). The resources decrease took place also because of

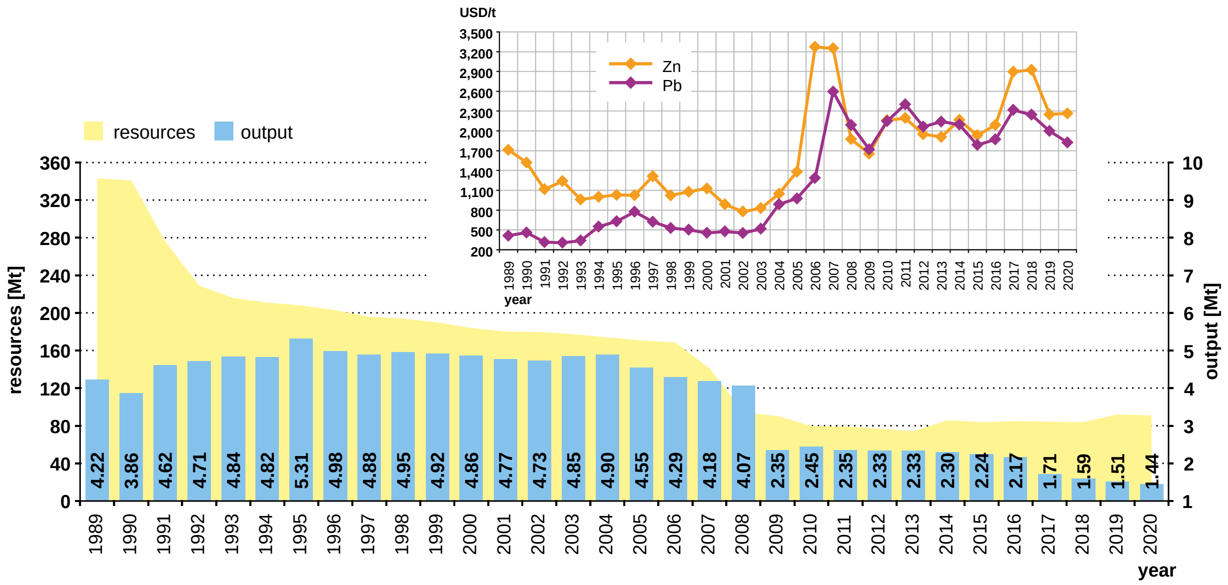


Figure 9.9.1. Zinc and lead ores anticipated economic resources, output and annual prices 1989–2020 (LME)

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021). Prices according to World Metal Statistics Yearbook

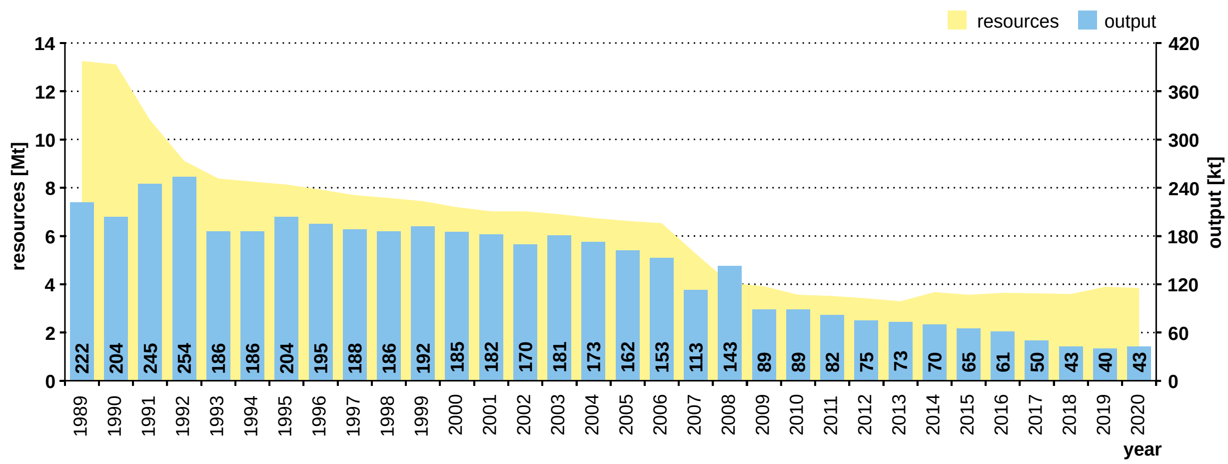


Figure 9.9.2. Metallic zinc anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

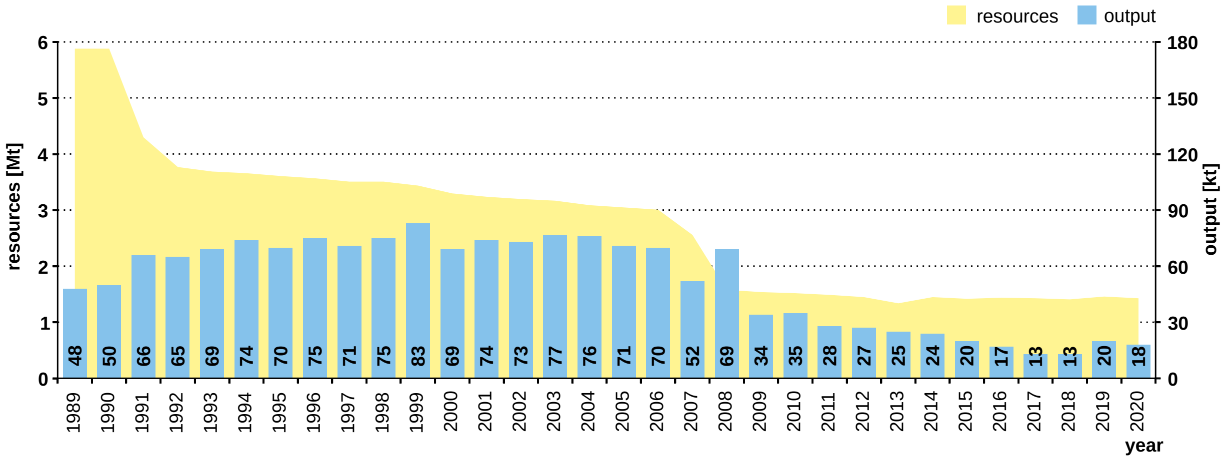


Figure 9.9.3. Metallic lead anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

exploitation and losses. In 2014 resources increased (by 11.73 Mt) mainly as the result of a new deposit being documented – Zawiercie 3 (replacing the Zawiercie I and Zawiercie obszar Zawiercie II deposits). In the 2016–2020 period ore resources grew to about 91 Mt as a result of: in 2016 (increase by 1.18 Mt) better exploration of the Klucze I deposit; in 2019 (increase by 8.19 Mt) the documentation of a new deposit Laski 1 (the Olkusz region) and more detailed exploration of the Zawiercie 3 deposit. The resources decreased in 2020 by 1.17 Mt of ore (1.27%) as a result of exploitation and losses.

In 2020, exploitation of ore decreased by 75 kt (4.97%) in comparison with 2019 and amounted to 1.44 Mt. There were 3 deposits being exploited: Klucze I (509 kt of ore), Olkusz (360 kt) and Pomorzany (565 kt). Looking back, the exploitation of Zn-Pb ores was quite stable, at about 4–5 Mt in the years 1989–2008, and then decreased rapidly to about 2 Mt (Fig. 9.9.1). This decrease in 2009 took place due to the closure of the Balin-Trzebionka mine (the Chrzanów area). The 2016–2020 period brought another negative tendency in the exploitation to the lowest point attained in 2020. In 2017 output decreases were recorded in 2 out of the 3 exploited deposits – most significantly from the Pomorzany deposit (by 575 kt). The next year was characterized by decreasing exploitation from the Klucze I and Olkusz deposits, whereas in 2019 and 2020 a similar tendency occurred for the Olkusz and Pomorzany deposits. The exploitation was finished in all deposits in 2020 and concessions expired as of 1st of January, 2021 due to the exploited deposits becoming depleted of resources.

Figure 9.9.1 presents zinc and lead prices. The prices remained quite stable until 2003, and then increased significantly in 2004–2007. This was due to the declining supply to the international market (as a result of liquidation or production suspension of mining plants). Simultaneously, there was a growing demand from the Asian markets, especially China, whereas stocks were reduced. The next 2 years brought a decrease in prices due to supply surplus. Prices increased in 2010 and 2011 due to growing demand, which in the next 4 years decreased slightly and the prices declined to below 2,000 USD/t. In 2016, both zinc and lead prices rose to 2,091 USD/t and 1,871 USD/t, respectively – the biggest triggers for this growth was the credit-fuelled construction boom that underpinned demand in China and the possibility of an announcement of a big push for infrastructure spending in the United States. In 2017, the price of zinc hit the highest point in over a decade of supply concerns – the average annual price increased to 2,894 USD/t, and for the same reason lead price grew to 2,318 USD/t. In the next year (2018) the average price of zinc rose to 2,925 USD/t as metal supply fell short of demand. Similarly, the lead market also posted a supply deficit in 2018, but production rose in Europe and the price fell to 2,244 USD/t. Due to a decline in demand for base metals throughout 2019, the prices of zinc and lead experienced slumps. The ongoing trade war between the United States and China has had a significant impact on metal demand. Therefore, the average annual price of zinc fell to 2,249 USD/t, while the lead price fell to 1,998 USD/t. In the last year (2020) the price of zinc slightly grew – to 2,265 USD/t – demand from end-user industries fell due to lockdown and quarantine measures. This in turn led to a sharp rise in zinc inventories at the exchanges. Lead prices increased at the beginning of the year on the back of a potential trade deal between the United States and China, but as COVID-19 spread around the world, the metal's price plummeted. The annual average price dropped in comparison with 2019 by 174 USD/t to 1,824 USD/t.

The figures 9.9.2 and 9.9.3 present the anticipated economic resources and the magnitude of output of metallic zinc and lead, in Poland, in the 1989–2020 period. Tendencies, especially regarding resources, are similar to the changes occurring for Zn-Pb ores decreasing to the lowest point in 2013 – 3.30 Mt of metallic zinc and 1.34 Mt of metallic lead. The following years brought a slight increase in resources – to 3.85 Mt of zinc and 1.43 Mt of lead in 2020. The output of metallic zinc attained the highest point in 1992 (254 kt) and was characterized by slight fluctuations until 2003. Then it fell significantly within the next 4 years (to 113 kt in 2007) and increased by 30 kt in 2008. Then, a declining tendency was observed until 2019, and a slight growth was noted in 2020 – amounting to 43 kt. The output of metallic lead increased from 48 kt in 1989, to 83 kt in 1999 – the highest point in the presented period. It then was fluctuating until 2006 and – similarly to zinc exploitation – fell significantly, by 18 kt in 2007. The next year brought a visible increase and followed by a declining tendency until 2017. The lowest recorded output amounted to only 13 kt (in 2017 and 2018). In the 2019–2020 period it amounted to 20 kt and 18 kt, respectively to the years.

10. Chemical raw materials

10.1. Barite and fluorspar

R. Bońda

Currently, due to its high specific gravity, **barite** ($BaSO_4$) is used mainly as a weighting agent in well drilling. Its use by the paper, chemical and paint industries is gradually shrinking being replaced by artificially produced titanium white (titanium dioxide).

Fluorspar (CaF_2) is used in the metallurgical, ceramics, and chemical industries. In metallurgy, in particular, it is used as flux (in steel production to aid the removal of impurities, and in aluminum production).

Barite and fluorspar occur in hydrothermal veins in paragenesis with metal sulfides. As they were jointly exploited from deposits located in the Lower Silesia region, therefore they are described together. Except for the deposits from the mentioned above region, barite accumulations are also known to occur in the Holy Cross Mts. (Plate 4).

The deposits located in the Lower Silesia region contain barite accumulations, which occur in veins of various length and width, generally very steeply dipping and representing fissure fills along faults. The mean content of $BaSO_4$ in these veins is about 80% and that of fluorspar – from a few to over a dozen percent. Generally speaking, the content of fluorspar generally increases with depth. In the Boguszów mine (in the vicinity of Wałbrzych) fluorspar can be spotted at the depth of 400 m. Moreover, the vein consists of barite in the north of the deposit, barite-fluorite in the central part, while becoming almost monomineralic fluorite at the southern end of the deposit. The mine exploiting the Boguszów deposit was completely flooded during the catastrophic flood of July, 1997. The mine was abandoned as a result of that damage and the deposit resources were reclassified as anticipated sub-economic. The next year – that is 1998 – mining operations in the Stanisławów mine were

Table 10.1.1. Barite and fluorspar resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
BARITE								
TOTAL RESOURCES	**5**	**5.67**	**0.10**	**1.81**	**3.75**	**–**	**0.89**	**–**
Including resources of non-exploited deposits								
Deposits covered by preliminary exploration	1	0.36	–	–	0.36	–	0.08	–
Including abandoned deposits								
Abandoned deposits	4	5.31	0.10	1.81	3.39	–	0.81	–
FLUORSPAR								
TOTAL RESOURCES	**2**	**0.54**	**–**	**–**	**0.54**	**–**	**0.06**	**–**
Including resources of non-exploited deposits								
Deposits covered by preliminary exploration	1	–	–	–	–	–	0.06	–
Including abandoned deposits								
Abandoned deposits	1	0.54	–	–	0.54	–	–	–

deemed insufficiently profitable and the mine was abandoned, however barite powder was still produced there until 2008, using waste material coming from the sedimentary ponds.

In the past, barite was also extracted from the Strawczynek deposit in the Holy Cross Mts. Currently, exploitation is abandoned. In this deposit barite occurs in the form of irregular nests and intergrowths within the carbonate rocks of the Lower Devonian, where the content of useful components is low (about 30%) and resources are relatively small.

Documented anticipated economic resources of barite are estimated at 5.67 Mt and those of fluorspar – at 0.54 Mt (Tab. 10.1.1). Current total domestic demand is covered by imports. For the last couple of years – due to an increasing demand for barite powder for well drilling – the reactivation of abandoned barite mines has been considered (mainly in the Stanisławów deposit as one of the biggest deposits in Europe). Prospects for increase of barite with fluorite resources should be associated with secondary tectonic zones along the Intra-Sudetic Fault: in the western extension of the Jeżów Sudecki deposit, located between the towns of Jeżów and Radomierz, and in the northern extension of the Jedlinka deposit. Prognostic resources of barite amounted to 2.5 Mt and prospective resources to 1.67 Mt. On the other hand, prognostic resources of fluorspar were estimated at 0.29 Mt and prospective resources – 0.10 Mt. as of 31.12.2018 (Sroga, 2020a). In the 2015–2020 period resources of both aforementioned raw materials have not changed.

10.2. Clay raw materials used in the production of mineral paints

R. Bońda

Clay raw materials used in the production of mineral paints come as powder and earthen iron oxide and hydroxide minerals, containing other additions of clayey minerals. There are several coloristic variants and their traditional names are: raddle – yellow or red, umbra – dark brown, terra di Siena – camel and ochre – goldbrown. These pigments are used in the production of oil paints, varnishes, enamels, putties etc. The production of natural pigments has lost significance over time, due to artificially produced pigments being used more often – they are characterized by more stable physical-chemical properties.

In Poland' only 2 deposits of ochre, clay and ochre claystone have been documented so far: Buk in the Mazowieckie voivodeship and Baczyna in the Świętokrzyskie voivodeship (Plate 4). In these deposits, within the clayey sediments of the Rhaetian–Toarcian, ochre occurs in the form of lens accumulations. In the Baczyna deposit there are 3 types of ochre occurring, documented in a C_1 category (total anticipated economic resources estimated at 578.1 kt): yellow, red and brown. Nevertheless, this deposit has never been exploited. The Buk deposit was exploited as late as 1976, but production was abandoned due to the depletion of resources. Nowadays, there are only anticipated sub-economic resources documented in the deposit (148 kt).

10.3. Diatomite rock

R. Bońda

In Poland, diatomite rock (or diatomite) is considered as two separate categories: diatomite rock (here also called diatomite), and siliceous earth. This section discusses diatomite rock (or diatomite) as understood by its Polish definition.

Diatomite is a compact sedimentary rock, built mainly of diatom skeletons composed of amorphous silica – opal. Diatomites are widely used as filtration aids, absorbents for liquids, carriers for herbicides, fungicides and

Table 10.3.1. Diatomite rock resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**4**	**10.01**	**–**	**3.27**	**6.74**	**–**	**2.74**	**0.20**
Including resources of exploited deposits								
Deposits of operating mines	1	0.64	–	0.44	0.20	–	–	0.20
Including abandoned deposits								
Abandoned deposits	3	9.38	–	2.84	6.54	–	2.74	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

catalysts, thermal insulation and polishing materials. They are also used as a mild abrasive.

In the Leszczawka area (Carpathians) diatomite, with an average SiO_2 content at 72%, occurs in the Menillite Series of the Krosno Beds. Products obtained from this raw material have fairly limited usability. Their major uses include the production of light building aggregates and carriers for herbicides and fungicides. It should be noted that technological tests indicated that an appropriate process (grinding and calcination) may improve a quality of this raw material up to that of proper diatomites.

Until now, however, no typical diatomite with SiO_2 content exceeding 80% have been found in Poland, therefore, in spite of differences in origin and mineralogical composition, siliceous earth is treated as a substitute for diatomite. Siliceous earth is discussed in a separate section of this publication.

Anticipated economic resources of diatomite are estimated at slightly above 10 Mt (Tab. 10.3.1). Since 2000 only one deposit – Jawornik – has been exploited. Extraction of diatomite remains small-scale and amounted to 0.81 kt in 2020.

Except for the documented deposits, there are possibilities of significantly increase the current known resources of the subject raw material. Prospective resources of diatomite rock in the Leszczawka area are estimated at about 10 Mt (Wołkowicz, 2020a). The chances for the discovery of new large diatomite deposits seem to be much higher in the case of the Menillite Series of the Krosno Beds, in the areas of Godowa, Błażowa–Piątkowa–Harta–Bachórz and Dydynia–Krzywe (Podkarpacie voivodeship). In the area where diatomite rock occurs, one can also find the prognostic area of Borek Nowy indicated, as well as 4 prospective areas close to: Futoma, Huta Poręby, Dobrzanka-Borownica and Leszczawka-Kuźmina. Unfortunately, the raw material located within the documented deposits is low quality, which results in minor-scale investment and interest in it.

10.4. Potassium-magnesium salt

G. Czapowski

In Poland, the distribution of potassium-magnesium salt is limited by the extent of the Zechstein salt formation. Together with rock salt, they form 2 separate lithostratigraphic units – the Older and Younger Potash units of the Zechstein. The units are traceable on the Polish Lowland where they were recorded in countless drillings, as well as in several salt structures in central Poland, and in layers in the south-western part of the Fore-Sudetic Monocline (Plate 4).

The anticipated economic resources of the 5 documented deposits of potassium-magnesium salt were estimated at over 686 Mt (16.31 Mt increase from 2016) and anticipated sub-economic resources at nearly 19 Mt (1.47 Mt decrease; Tab. 10.4.1).

The Puck Bay sulfate (polyhalite) salt deposits form the bulk of the aforementioned resources. The deposits in the Puck Bay area are of the sulfate (polyhalite) salt type, with polyhalite occurring in a form of early diagenetic minerals developed in anhydrite layers, which underlay and intercalate and overlay the oldest rock salt bed of the Zechstein. Polyhalite inclusions are present as irregularly disseminated nests and aggregate intergrowths in a depth interval from 740 to 900 m. K_2O content ranges from 7.7 to 13.7% in said depth interval. The deposits situated along the rim of the Puck Bay rock salt deposit were covered by preliminary exploration in the years 1964–1971. Their steady indicated resources were estimated in the 1970's at 597 Mt, assuming a regular distribution of polyhalite mineralization.

Small accumulations of potassium salt (more than 89 Mt) were identified along the eastern margin of the Kłodawa salt dome, where potassium chloride type salts (carnalite and sylvine) occur in rocks of the Younger Potash unit, steeply inclined (at the angle of 70°) and folded and locally squeezed and crumpled. The chloride salts are strongly contaminated with clay matter and sulfates. Mean contents of K_2O and MgO are 8.5 and 8.1%, respectively. The potassium salt accumulations are of minimal economic interest due to a high variability in strata thickness (from a few to 50 m) and problems in processing of the raw material. The salts were exploited seasonally until the year 2000, when 1,400 t were mined. In the following years this part of the salt deposit became abandoned.

Potassium salt deposits are explored to the depth of 1,200 m. The thickness of 2 m is accepted as minimum, providing that the weighted average K_2O content in a deposit is not lower than 8%. Potassium-magnesium salt resources have slightly changed since 2016 (anticipated economic resources increased by 16.31 Mt and anticipated sub-economic resources decreased by 1.47 Mt) due to the verification of resources in the newly established Kłodawa 1 deposit in 2016.

In 2020, predicted resources of stratiform potassium-magnesium salt occurrence were estimated at 3,638 Mt (Czapowski *et al.*, 2020), including prognostic resources (to a depth of 1.2 km) estimated at 821.5 Mt and prospective resources (in a depth interval between 1.2–2.0 km) of up to 2,816.6 Mt (Czapowski, Bukowski, 2015; Czapowski *et al.*, 2015).The prospective resources situated in the Kłodawa dome amounted to 300 Mt at a depth interval between 1 and 2 km (Czapowski, Bukowski, 2011).

Table 10.4.1 shows resources and a current state (as of the end of 2020) of exploration and development of potassium-magnesium salt. The data refer to exploitable resources (that is except from those remaining in protective pillars).

Potassium-magnesium salts have not been exploited in Poland since 2000 (that year 1 kt of these salts were excavated in the Kłodawa salt dome) and all such salts, required for agriculture (fertilizers), are currently being imported.

Table 10.4.1. Potassium-magnesium salt resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**5**	**686.15**	**6.92**	**23.60**	**655.63**	**–**	**18.85**	**3.46**
Including resources of non-exploited deposits								
TOTAL	5	686.15	6.92	23.60	655.63	–	18.85	3.46
1. Deposits covered by detailed exploration	1	89.12	6.92	23.60	58.61	–	–	3.46
2. Deposits covered by preliminary exploration	4	597.03	–	–	597.03	–	18.85	–

10.5. Rock salt

G. Czapowski

Major Polish rock salt deposits are related to the Miocene and Zechstein halite formations.

Deposits of the Miocene formation are situated in a belt extending from the Silesia region to Wieliczka and Bochnia and further eastwards up to the Poland–Ukraine border (Plate 4) and running close along to the present-day frontal overthrust of the Carpathian Mts. Foredeep. In the Wieliczka area, salt was produced from the Middle Ages right through into the 20th century. Exploitation of these deposits ended in 1996 when salt mining was phased out in the Wieliczka mine. Proven resources of the Miocene rock salt deposits in 2020 are estimated to be over 4.36 bnt, accounting for 3.9% of domestic resources. However, the geological structure of these deposits is very complex due to intense folding (except for the Rybnik–Żary–Orzesze deposit which is situated in a tectonic trough). That complexity of geological structure, along with significant variations in salt quality and the high risks of water flooding and methane inflow to active mining areas, were all reasons why further mining of these deposits became practically uneconomic. The Wieliczka mine was included on the UNESCO World Heritage list in 1978. Nowadays, the Wieliczka and Bochnia mines are great tourist attractions and recreation centers.

The Zechstein halite formation is at present the major source of salt mined in Poland. Salt-bearing series are distributed throughout 2/3 of the country's area, mainly on the Polish Lowland (Plate 4). In the Late Permian these areas were occupied by an evaporitic epicontinental basin which was the place of accumulation of salt sediments with a total thickness of over 1,000 m. Bedded rock salt accumulations were explored down to a depth of 1,000 m in the marginal parts of the basin (in areas of the Łeba Elevation and the Fore-Sudetic Monocline). The anticipated economic resources of said deposits are estimated at over 26.1 bnt and account for 23.3% of the total domestic salt resources. In turn, in the axial part of the basin (Central Poland), the salt-bearing series are buried at depths up to 7 km, locally rising almost to the surface in salt dome- and pillow-like structures. The salt structures occur in the belt stretching from the Wolin Island in the north-west to the areas in the vicinity of Bełchatów in the south-east. Deposits of rock salt and potassium-magnesium salt were explored and documented in a number of the shallowest of these structures. Proven anticipated economic resources of deposits related to the salt structures were estimated in 2020 at over 81.3 bnt, which account for almost 73% of domestic salt resources. Exploitation of the Zechstein salt deposits gives 100% of the current domestic production of salt.

Large bedded rock salt deposits were also explored in the overburden of the Sieroszowice copper ore mine (Bądzów salt deposit established and produced crushed road salt since 2013) and other copper ore deposits in the Fore-Sudetic Monocline.

Bedded rock salt deposits are explored down to a depth of 1,200 m, provided that a deposit series (including partings) is at least 30 m thick and has a minimum weighted mean of NaCl in the deposit series and partings is estimated at >80%. In accordance with the Polish regulations, salt deposits related to dome and pillow salt structures are explored down to 1,400 m, provided that a distance between the top surface of a salt deposit and its salt mirror is not smaller than 150 m. The remaining requirements are the same as for bedded deposits. At present, salt deposits begin to be treated as geological objects especially advantageous for the construction of underground facilities used for oil and natural gas storage (the operating cavern gas storage facilities, the Mogilno II in the Mogilno diapir and the Kosakowo gas storage facility in the Mechelinki stratiform deposit put into operation in 2014 and planned to be enlarged) and liquid fuel (the abandoned caverns in the Góra diapir) and for the safe disposal of hazardous materials.

In 2020 the anticipated economic resources of rock salt (excluding those within protective pillars) documented in 19 deposits, amounted to 111.85 bnt (increased by 26,47 bnt from 2015), anticipated sub-economic resources estimated at 10.4 bnt (decreased by 11.72 bnt from 2015) and economic resources in place – at over 1.74 bnt (Tab. 10.5.1). In 2020, the total salt production (prevailed brine produced by leaching the Mogilno and Góra mines, subordinate volume of crushed salt is also extracted from the Kłodawa and Bądzów underground mines) from 6 deposits amounted to 3.64 Mt.

Table 10.5.1 shows resources and the current state (as of 2020) of exploration and development of domestic rock

Table 10.5.1. Rock salt resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**19**	**111,850.03**	**578.45**	**55,392.39**	**55,385.69**	**493.51**	**10,401.43**	**1,740.42**
Including resources of exploited deposits								
TOTAL	6	14,923.05	561.44	9,192.52	5,169.09	–	–	1,740.42
1. Deposits of operating mines	5	9,229.43	561.44	5,533.91	3,134.08	–	–	1,640.73
2. Deposit exploited temporarily	1	5,693.61	–	3,658.61	2,035.01	–	–	99.69
Including resources of non-exploited deposits								
TOTAL	10	96,739.10	–	46,137.20	50,108.40	493.51	10,214.18	–
1. Deposits covered by detailed exploration	3	27,642.03	–	24,733.43	2,908.60	–	8,026.04	–
2. Deposits covered by preliminary exploration	7	69,097.07	–	21,403.77	47,199.80	493.51	2,188.14	–
Including abandoned deposits								
Abandoned deposits	3	187.88	17.01	62.67	108.20	–	187.25	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

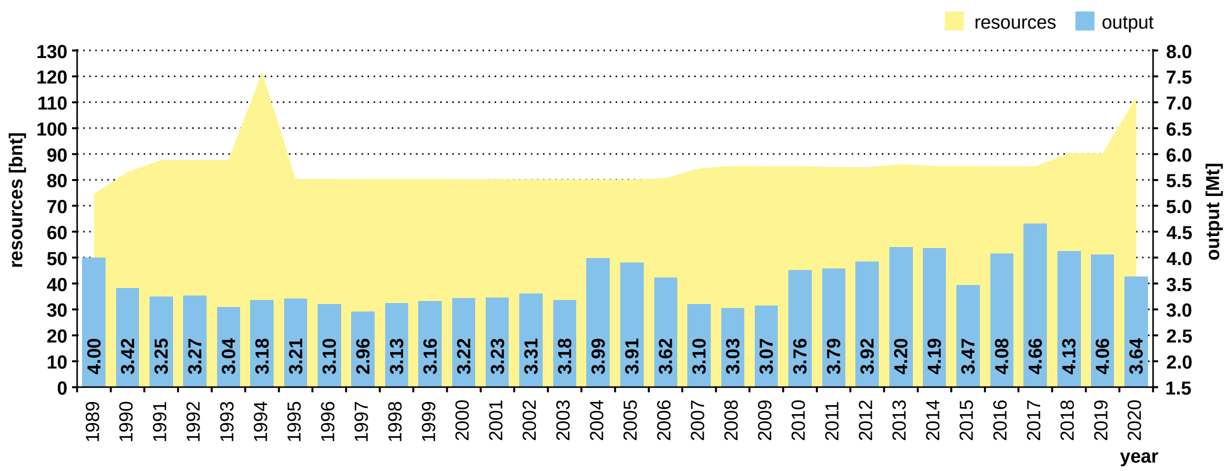


Figure 10.5.1. Rock salt anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

salt deposits. Data refer to resources excluding those within protective pillars.

In the 1989–1992 period, the anticipated economic resources of rock salt in Poland (excluding these within protective pillars) slowly increased from about 74.64 bnt to 87.77 bnt and remained almost the same until 1994 (Fig. 10.5.1). That year, significant growth, to over 121 bnt, resulted from including the estimated salt resources of 5 new copper deposits in the Fore-Sudetic

Table 10.5.2. Rock salt anticipated economic resources, output and production in 2016–2020

Year	Anticipated economic resources [bnt]	Output [Mt]	Rock salt production from salty mine waters [kt]
2016	85.35	4.08	68.0
2017	85.28	4.66	62.7
2018	90.36	4.12	67.0
2019	90.32	4.06	68.9
2020	111.85	3.64	66.3
TOTAL ROCK SALT OUTPUT (2016–2020)		**20.56**	**332.9**

Monocline area, in which salt was the associated raw mineral. In the following year (1995), said resources were again excluded and until 2006 the total volume of anticipated economic resources remained at a stable level of about 80 bnt. More precisely, from 2007 to 2009 the resources increased to 85.4 bnt, mainly due to a reassessment of the Mogilno I, Mogilno II (in Mogilno salt dome), and Mechelinki (near the Bay of Puck) resources. In the next 3 years, the volume of resources remained almost constant (below 84 bnt). Their increase to over 86 bnt in 2013 was an effect of activating the new Bądzów salt deposit with resources estimated at about 740 Mt. Later, a slight decrease to the actual volume resulted from salt production (Fig. 10.5.1). In the 2016–2020 period, a significant increase of anticipated economic resources of rock salt in Poland from about 85.35 to 111.85 bnt (Tab. 10.5.2) resulted from a new estimate of the resources in 3 salt deposits: Damasławek (2020), Kłodawa 1 (2016), and Lubień (2018).

Rock salt production had significantly changed over the 1989–2015 period – the main factor was the domestic demand for brine used for calcined soda and crushed salt production. From 4 Mt in 1989, the output lowered to a critical 2.96 Mt in 1997, due to the aforementioned effect which lower production in still existing mines and caused the abandonment of salt extraction in the Wieliczka mine (Fig. 10.5.1). The next 6 years recorded fluctuating output (from 3.13 to 3.31 Mt), but in 2004 there was a spike in production causing significant growth to almost 4 Mt. In the 2005–2009 period, the production decreased by 25% to about 3 Mt. From 2010, a successive increasing tendency in annual salt production was observed (due to initiating cavern leaching in the Cavern Underground Gas Storage Kosakowo facility located in the Mechelinki deposit, and due to the commencement of salt extraction from the new Bądzów deposit) to over 4 Mt in the 2013–2014 period. The reduction in output in 2015, to less than 3.5 Mt, was the result of lowered production of brine from leaching of mines (Mogilno and Góra) and of crushed salt from underground mines (Kłodawa and Bądzów), as a response to a lower demand for road salt (warmer winters). Furthermore, the completion of the first set of gas caverns in the Cavern Underground Gas Storage Kosakowo facility decreased the production of brine volume (decreased to that of the Puck Bay). During the next 4 years (2016–2019) the total rock salt output from 6 active mines was almost constant (4.06–4.66 Mt), with a small decrease (to 3.64 Mt) registered in 2020 (Tab. 10.5.2). The total volume of exploited rock salt in that period was 20.56 Mt.

A small amount of rock salt, evaporated by the Dębieńsko Desalination Plant Ltd. from salty waters delivered by the Upper Silesian coal mines, fluctuated in the 2004–2015 period from 60 kt (2006–2007) to over 92 kt (in 2009), and to 81.4 kt in 2015. Later (2016–2020 period), this volume ranged only slightly from 66.3 to 68.0 kt and the total volume of produced rock salt amounted to about 333 kt (Tab. 10.5.2).

In 2020, Poland exported over 264 kt of rock salt and brine, but imported over 475 kt.

In 2020 (Czapowski *et al.*, 2020), the predicted resources of rock salt, in both stratiform and diapiric occurrences, were estimated at about 4,058.96 bnt, including prognostic resources (up to a depth of 1.2–1.5 km) amounting to about 951.44 bnt, and prospective resources (within the depth interval of 1.2–2.0 km) of up to 3,037.67 bnt (Czapowski, Bukowski, 2015; Czapowski *et al.*, 2015). Zechstein salt deposits, with total resources estimated at about 4,052 bnt, dominate over Miocene salt deposits (6.9 bnt).

10.6. Siliceous earth

R. Bońda

Siliceous earth possesses similar physical features to diatomite, and therefore, finds similar use in the industry. It is used as a carrier for catalysts in chemical processes, and for mineral fertilizers and herbicides, pesticides and fungicides in agriculture, as well as a raw material for refining and filtration, and a constituent in synthetic mass molding. Siliceous earth differs from diatomite in the mode of origin, as it is a product of decalcification of sedimentary rocks (gaizes) mainly built of opal, a mineraloid gel.

Deposits of siliceous earth occur mainly in tectonic troughs at the margin of the Holy Cross Mts. (the Piotrowice, Dąbrówka – pole I and Dąbrówka – pole II deposits) and in the Lublin Upland (the Lechówka and Lechówka II deposits), in the form of sedimentary covers overlain by Oligocene rocks (Plate 4).

The Lechówka II deposit is the only periodically exploited siliceous earth deposit in Poland and its output remained negligible, changing from a few tons in the 1998–2002 period to none in 2013. Then, in 2014, the deposit was abandoned. Exploitation of the remaining deposits has been phased out in the last decades due to the unsatisfactory quality of the obtained raw material, mainly useful for making insulation powder. Economic resources amounted to 2,223 kt in 2020 (almost 50% in A+B+C_1 categories). Domestic demand for siliceous earth is fully covered by import. In Poland, there is only one prognostic area for the occurrence of siliceous earth that has significant resources (3.13 Mt) – indicated in the vicinity of the Janów village, near Chełm (Wołkowicz, 2020b).

Table 10.6.1 shows resources and the current state of exploration and development of siliceous earth deposits in Poland.

Table 10.6.1. Siliceous earth [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**5**	**2.22**	**1.09**	**1.13**	**1.01**	**–**
Including abandoned deposits						
Abandoned deposits	5	2.22	1.09	1.13	1.01	–

10.7. Native sulfur

R. Bońda

Native sulfur deposits occur in the vicinities of the towns of Tarnobrzeg (Osiek, Baranów, Machów and Jeziórko deposits), Staszów (Solec and Grzybów deposits) and Lubaczów (Basznia deposit) in the northern part of the Carpathian Foredeep (Plate 4). There are a few sources of native sulfur. Lesser amounts are found near volcanic vents and fumaroles; however the majority of it was created in a process of sulfate reduction (mainly gypsum and anhydrite) with the participation of bacteria and hydrocarbons. The sulfur occurs in the above mentioned areas in the form of fissure and small cavity fillings in the Neogene (Miocene – Tortonian) chemical rocks, mainly post-gypsum limestones. Sulfur content in these rocks may reach up to 70%, with an average content ranging from 25 to 30%.

When documenting sulfur deposits the parameter limits that define anticipated economic resources are: minimum sulfur content in the sample contouring a deposit of 10%, minimum average sulfur content in deposit bed of 10%, minimum deposit grade of 75m% and the maximum depth of the deposit base at 400 m.

Table 10.7.1. Native sulfur resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	15	494.08	28.37	409.29	56.42	–	35.78	14.47
Including resources of exploited deposits								
Deposits of operating mines	2	14.55	0.89	13.67	–	–	0.68	14.47
Including resources of non-exploited deposits								
TOTAL	7	256.69	1.26	199.91	55.53	–	14.64	–
1. Deposits covered by detailed exploration	4	158.94	1.26	157.68	–	–	5.89	–
2. Deposits covered by preliminary exploration	3	97.75	–	42.23	55.53	–	8.76	–
Including abandoned deposits								
Abandoned deposits	6	222.83	26.23	195.71	0.89	–	20.46	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

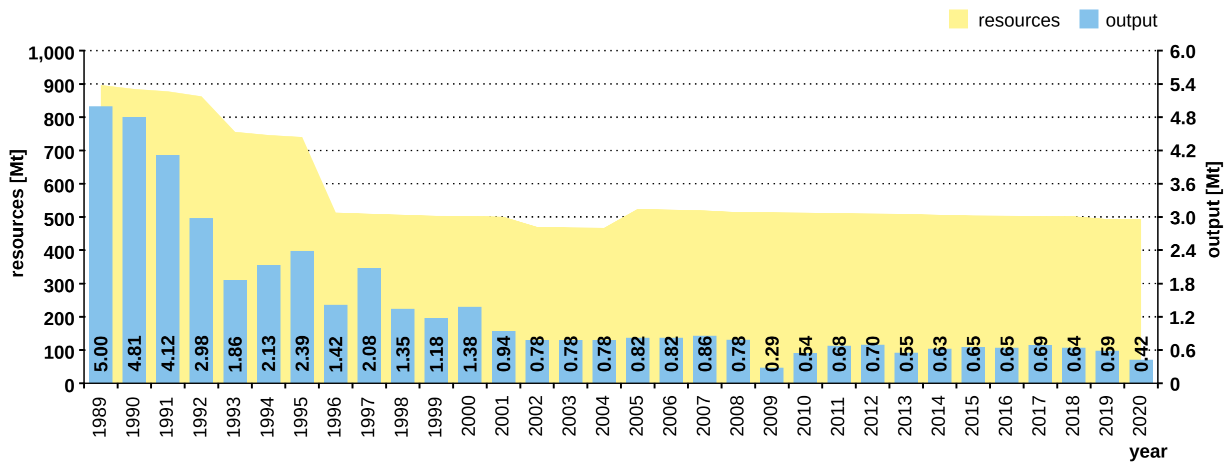


Figure 10.7.1. Native sulfur anticipated economic resources and output in 1989–2020

According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

In 2020, the anticipated economic resources of native sulfur amounted to about 494 Mt (Tab. 10.7.1), of which the majority occur within the vicinity of Tarnobrzeg (about 427 Mt). In 2015, there was a new deposit documented – Basznia-1 (with geological resources estimated at 6,056 kt). The deposit is located in place of the Basznia deposit abandoned in 1993. In 2017, an exploitation concession issued and a deposit development plan, were approved for the Basznia-1 deposit, which resulted in native sulfur economic resources increasing by about 6 Mt. Exploitation of the given deposit started in 2019. Within the last several years anticipated economic resources of native sulfur have been systematically decreasing due to exploitation and losses during production (Fig. 10.7.1). The resources amounted to almost 900 Mt in 1989. In 1992 and 1993, the resources decreased as a result of the approval of smaller resources in Machów I, Jamnica and Machów II. Until 1995 the resources of native sulfur presented in “The balance…” included resources within protective pillars, whereas from 1996 onward the resources excluded such pillars – it resulted in a significant decline in resources (by more than 200 Mt). In 2002, a recorded decrease in resources resulted from a reassessment of resources within the Jeziórko-Grębów-Wydrza deposit. In 2005 the registered growth by 57 Mt was due to the Grębów deposit resources being included into “The balance…”. Since then, the anticipated economic resources of native sulfur have been quite stable – slightly below 500 Mt, with only minor decreases resulting from exploiting of the Osiek deposit and (in recent years) the Basznia-1 deposit.

Recently, output of native sulfur has been mined only from the Osiek deposit, using the Frasch process – in 2020 it amounted to 417.48 kt. The Osiek mine is the last active large native sulfur mine left in the world. Native sulfur is obtained also – however in minor amounts – from the Basznia-1 deposit. In 2020, exploitation amounted to 4.9 kt, which accounts for slightly above 10% of total domestic output. The total output in Poland in 2020 amounted to 422.38 kt. The pace of exploitation of the Osiek deposit remained in the last couple of years in the range between 500 and 700 kt. In 2009, due to a rapid reduction in exported sulfur and declining domestic demand, there were only about 260 kt mined. Also in 2020, there was a declining tendency recorded and output amounted to slightly above 400 kt.

Considering a longer period of time, the sulfur output was equal 5 Mt in 1989, and between 1989 and 2020 dropped more than 10-fold, as a result of further mine closures. In the 1990’s there were 5 native sulfur mines operating, whereas currently there are only 2, of which only exploitation of the Osiek deposit is of significant importance.

Except for the exploitation from underground deposits, native sulfur is in small amounts being obtained from the volcanic deposits. The other sulfur source is the recovery of the sulfuric acid in the processing of copper ores, and lead and zinc ores. Such recovery is of limited economic importance mainly due to environmental protection issues.

Prognostic resources of native sulfur are currently being assessed at 82 Mt, whereas hypothetical resources at 231 Mt (Gąsiewicz, 2020).

Sulfur as a by-product. Over the last couple of years, native sulfur production has been significantly declining in the world economy. The production of the native sulfur in Poland is quite expensive, therefore it is being replaced by much cheaper sulfur obtained from sour gas and oil fields. In Poland there are 4 sour gas and oil fields documented (Plate 4) with total resources amounting to 365.34 kt in 2020 (Fig. 10.7.2). In 1996, there were sulfur resources documented in the BMB (Barnówko–

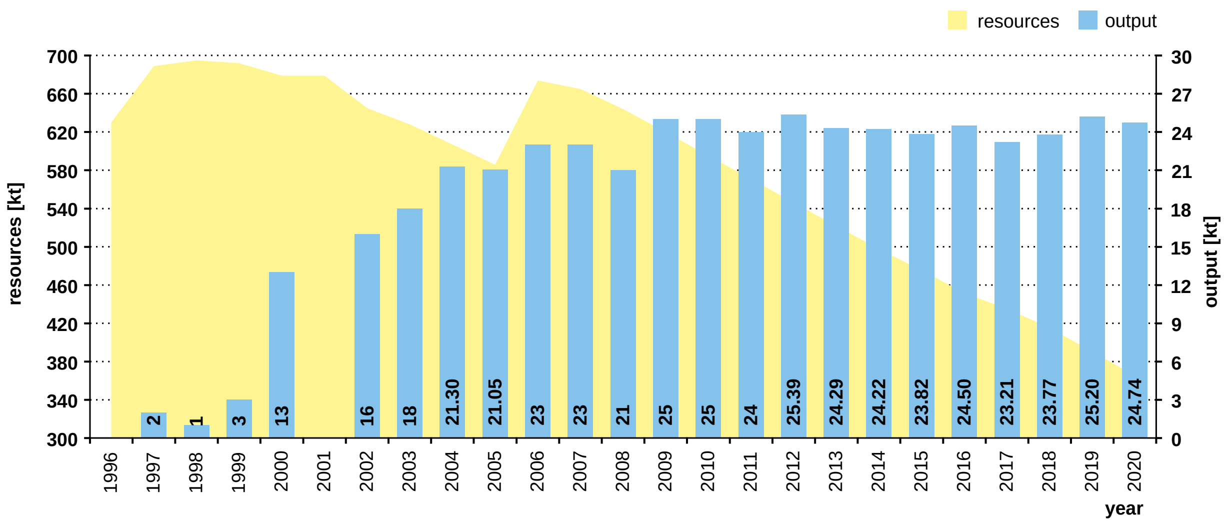


Figure 10.7.2. Sulfur as a by-product anticipated economic resources and output in 1996–2020

Varied data accuracy results from source data. According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Mostno–Buszewo) and Zielin oil-gas fields. In the next year the resources were documented in the Cychry high-nitrogen natural gas field, whereas in 1998 in the Górzyca oil-gas field. In 2006 there was a new documentation with recalculated resources approved for the BMB field and it resulted in a growth of total sulfur resources from 586 to 674 kt. Since 2007, the resources of sulfur as a by-product have been systematically declining due to its recovery from exploited hydrocarbons.

In 2020, the recovery of sulfur from Polish sour oil and gas fields is being carried out in 4 fields and amounted to 24.74 kt. Since 1997, sulfur has been obtained from the Zielin and BMB fields, whereas in 1998, additional exploitation commenced in the Cychry field. In 2005, temporary exploitation started in the Górzyca field. Since 2006, the sulfur recovery resulting from the desulfurization of oil and gas fields has been fluctuating within the range of 23–25 kt per annum and is of minor importance to the domestic economy. In 2020, there were 23.6 kt of sulfur recovered from the BMB field, accounting for 95% of the total recovery that year.

11. Rock raw materials

11.1. Amber

D. Brzeziński, A. Malon, K. Szamałek

Amber. Over the ages, amber has been the most famous and widespread jewelry stone in Poland, therefore the Polish amber industry occupies the position of world leader and is characterized by original jewelry of outstanding quality and other artistic products designs made of this raw material. Apart from jewelry, amber can be used for the production of paints, lacquer, pigments, plastic, solvents and plasticizers. Amber can be also used in alternative medicine and in the pharmaceutical-cosmetics industry due to its germicidal and antiseptic properties.

In Poland numerous amber accumulations are documented in Tertiary sediments (*in situ* accumulations) and Quaternary accumulations (secondary accumulations). Apart from the accumulations within a beach area of the Baltic Sea (especially its eastern part), amber deposits are located in the Pomorskie and Lubelskie voivodeships. Documented deposits in Tertiary sediments (*in situ*) occur within marginal zones of the Eocene Sea, in the so-called chłapowsko-sambijska delta (the northern zone in the vicinity of Chłapowo) and in the so-called Parczew delta (the southern zone in the vicinity of Parczew). In the Tertiary sediments, ambers have been documented in the vicinity of Możdżanowo, near Ustka, within the Upper Eocene sand and gravel. They form a glacial ice float within the Quaternary sediments. The Quaternary amber-bearing accumulations can be detected in sediments relocated by the glacial and post-glacial rivers from degraded Tertiary deposits, mainly the chłapowsko-sambijska delta sediments. Minor amber concentrations are also encountered on the Baltic beaches from Kołobrzeg to the eastern border of Poland on the Vistula Spit where amber occurs in beach fossil sediments and on recently formed beaches.

Prospective resources of amber are difficult to assess due to an insufficient paleogeographical and facies exploration of amber-bearing sediments. Locally, it is also difficult because of the impoverishment or depletion resources, as a result of illegal exploitation (Kramarska *et al.*, 2020). As a reserve of amber it is possible to consider prognostic resources within fine-grade Eocene sediments occurring in the northern part of Lubelszczyzna region. The amount of these resources can be evaluated at 22 kt. Significant amber occurrences can also be expected within the Quaternary sediments in the area of the Gdańsk shore, especially in regions of traditional exploitation on the Vistula river delta. A possibility of developing other prospective areas is unlikely due to the deposit layer depth, small sizes, dispersion and a potential conflict between exploitation and environmental protection.

Anticipated economic resources of amber, as of the end of 2020, increased by 2,034.19 t in comparison with the previous year and amounted to 3,580.84 t. This significant increase in resources was the result of documenting new resources in the Niedźwiada II deposit in the vicinity of Górka Lubartowska, located in the Lubelskie voivodeship. Initially, in 2018, there were only glauconite-bearing sediments documented, then in 2020 accompanying raw materials were documented: amber, phosphorite concretes and glass sand and sandstones.

In the last 5 years, the number of amber deposits increased more than twofold and anticipated economic resources more than threefold. New resources have been documented mainly within the vicinity of the Górka Lubartowska in the Lubelskie voivodeship (deposits: Niedźwiada II – 2,032.80 t, Brzeźnica Leśna – 298.02 t, Niedźwiada Kolonia I – 139.64 t. Górka Lubartowska-Niedźwiada – 98.00 t, Górka Lubartowska IX – 47.97 t, Górka Lubartowska-Leszkowice – 46.15 t, Górka Lubartowska VIII – 7.54 t, Leszkowice 1 – 4.40 t). There were also 2 small deposits documented within the Vistula river delta: Rybakówka with resources estimated at 1.03 t and Kąty Rybackie with resources estimated at 6.90 t (the deposit was documented during the implementation of the investment realization in a waterway connecting Vistula Lagoon with the Gulf of Gdańsk).

For a long time, amber output in Poland was minor, irregular and connected mainly with geological work aimed at searching for and exploring amber deposits. In 2016–2020 there were 4.24 t of amber obtained in the areas of Lubelskie, Pomorskie and Zachodniopomorskie voivodeships. At the end of 2016, exploitation of the

Table 11.1.1. Amber resources [t]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**18**	**3,580.84**	**2,131.23**	**1,449.61**	**24.70**	**80.52**
Including resources of exploited deposits						
Deposits of operating mines	1	85.00	0.00	85.00	–	20.78
Including resources of non-exploited deposits						
TOTAL	15	3,476.09	2,111.48	1,364.61	24.70	59.74
1. Deposits covered by detailed exploration	6	2,111.48	2,111.48	–	4.16	33.44
2. Deposits covered by preliminary exploration	9	1,364.61	0.00	1,364.61	20.54	26.30
Including abandoned deposits						
Abandoned deposits	2	19.75	19.75	–	–	–

Przeróbka-SL deposit was abandoned, as primary information on the quality of amber, as well as on the wealth of the deposit, were not confirmed. A minor amount of amber was also obtained during exploitation of sand and gravel from the Baltic Sea bottom of the Zatoka Koszalińska deposit (200 kg in 2017). Additionally, it is assumed that the annual output of amber collected from the Baltic Sea beaches is estimated at about 5–6 t. However, 2020 was a crucial year for amber mining in Poland. After works to divide the deposit and the end of building the processing plant, in June of 2020, an open pit mine of amber, sand and glauconite within the Górka Lubartowska-Niedźwiada deposit commenced its work. In 2020, 12.14 t of amber was exploited from this deposit, which is a record-breaking quantity.

Eocene glauconite-bearing sediments (sand and silt with glauconite) have been documented in the last few years, in which occurrences of amber were noted.

Glauconite-bearing sediments. The entrepreneurs in Poland have recently moved their attention to the use of glauconite-bearing sediments (sand and silt with glauconite) which are associated with feldspar-quartzitic and quartzitic sand deposits. So far, the glauconite-bearing sediment has not been documented as a mineral raw material and therefore is not included in the "Regulation by the Minister of the Environment on geological documentation of a raw material deposit excluding hydrocarbon fields" (dated the 1st of July, 2015 – Journal of Laws 2015, Item 987) – the parameter limits that define the deposit and its boundaries have not been defined. Thus – on the basis of the performed geological works – geologists documenting the glauconite-bearing sediment have initially determined the scope of the requirements for their documentation. The parameter limit criteria accepted for a glauconite deposit varied slightly in individual documentations, but mostly amounted to:

- a maximum documentation depth – 30 m;
- a minimum deposit thickness – 5 m;
- a minimum glauconite content – 10%.

The presence of iron oxides in glauconite makes it usable for the production of glass and vitreous shells with a wide range of colors, of ceramic pigments, and of colorful and vitreous ceramic and stone decorations. The sediments can also be used as a potential potassium source in agriculture, as a slow acting fertilizer with a significant content of the magnesium, iron and organic trace compounds. Moreover, due to its chemical features it can be used for water and sewage treatment technologies – to remove heavy metal contaminants.

There have been 6 deposits of the glauconite-bearing sediments documented so far: Brzeźnica Leśna, Górka Lubartowska IX, Górka Lubartowska-Niedźwiada, Lesz-

Table 11.1.2. Glauconite-bearing sediments [Mm^3]

glauconite-bearing sediments
glauconite

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	6	**9.03**	**9.03**	–	–	**1.00**
		1.30	***1.30***			***0.12***
Including resources of exploited deposits						
Deposits of operating mines	1	1.78	1.78	–	–	0.67
		0.21	*0.21*			*0.08*
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	5	7.25	7.25	–	–	0.34
		1.09	*1.09*			*0.04*

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

kowice 1, Niedźwiada II and Niedźwiada Kolonia I. All of these deposits are located in the Lubelskie voivodeship. The geological structure of the Górka Lubartowska area contains mainly Quaternary sand and lying below them the Upper Eocene silt and sand with glauconite (the so-called Parczew delta) in which occurrences of amber were also noted. These deposits were documented in: 2017 (2 deposits), 2018 (1) and 2019 (3).

The anticipated economic resources of the glauconite-bearing sediments, as of the end of 2020, amounted to 9.03 Mm^3, including 1.30 Mm^3 of glauconite (Tab. 11.1.2). The largest of them is the Brzeźnica Leśna deposit (3 Mm^3), while the smallest is the Górka Lubartowska IX deposit with about 0.5 Mm^3. There were 2 concessions issued – for the Górka Lubartowska-Niedźwiada deposit in 2018 (the exploitation started in 2019) and for the Górka Lubartowska IX deposit in 2020 (not yet exploited). The anticipated economic resources of the glauconite-bearing sediments slightly decreased by 0.1 Mm^3, including a decrease in glauconite by 0.01 Mm^3, in comparison with 2019. It was a result of exploitating the Górka Lubartowska-Niedźwiada deposit. In it, the glauconite-bearing sediments are the accompanying raw material for feldspar-quartzitic sand. The economic resources of glauconite-bearing sediments in Poland amounted to 1.00 Mm^3, including 0.12 Mm^3 of glauconite.

The output, from the only exploited Górka Lubartowska-Niedźwiada deposit, was estimated at 65,770 m^3 in 2020, including 7,890 m^3 of glauconite.

11.2. Bentonite and bentonitic clays

D. Brzeziński

Bentonites are clayey rocks that are formed as the result of a decomposition process (bentonitization) of volcanic glass, occurring in pyroclastic sediments, such as tuffs and tuffites. Bentonite is mainly composed of smectite group minerals (with a minimum montmorillonite content of 75%) accompanied by other clayey minerals and relicts sourced from a pyroclastic material. **Bentonitic clays** are similar to bentonites, containing – along with smectite minerals – a larger amount of other clayey minerals. Different uses of rocks rich in smectite group minerals depend on some common features such as: an ability to swell, susceptibility to a dispersion of water, high plasticity, an easy absorption of cations and organic substances from water solutions, an ability to form thixotropic suspensions. Thanks to these

Table 11.2.1. Bentonite resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**8**	**2.88**	**1.16**	**1.72**	**0.25**	**0.34**
Including resources of exploited deposits						
Deposits of operating mines	1	0.49	0.28	0.21	–	0.34
Including resources of non-exploited deposits						
TOTAL	5	2.33	0.87	1.45	0.25	–
1. Deposits covered by detailed exploration	3	1.40	0.87	0.53	0.25	–
2. Deposits covered by preliminary exploration	2	0.92	0.00	0.92	–	–
Including abandoned deposits						
Abandoned deposits	2	0.07	0.01	0.06	0.01	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

features and due to their susceptibility to various modifications, there are many ways of utilizing these rocks in: the foundry industry, the chemical industry, the ceramic industry, engineering and hydro-technical works, agriculture and as a component in drilling fluid. Most of bentonites in Poland are used traditionally in the foundry industry, drilling and in a new, strongly developing hygienic sorbents market (for animals). Primary bentonite (meaning an almost monomineralic montmorillonitic rock with a small admixture of other minerals) very seldom occurs in Poland. Various bentonitic clays with a relatively high content of non-clayey minerals are more common. The group of bentonitic raw materials contains: bentonitic, weathered basaltoid covers of in the Lower Silesia region, bentonitic clays in the Upper Silesia region, bentonitic clays in the Carpathian Foredeep, bentonitic and zeolite-bentonitic clays and clay-schists in the Carpathians (Plate 7).

Total prospective resources of bentonitic raw materials amount to over 43.626 Mt and occur in the Dolnośląskie (39.900 Mt), Świętokrzyskie (3.056 Mt), and Podkarpackie (0.670 Mt) voivodeships (Brański, 2020).

In 2020, anticipated economic resources of bentonitic raw materials amounted to 2.88 Mt, whereas economic resources to 0.34 Mt (Tab. 11.2.1). Exploitation of bentonitic mantle rock of basalt tuffs has been carried out from the Krzeniów deposit only. It has maintained production within a range of 0.45–3.21 kt per year for over 25 years. In 2020, the output amounted to 0.92 kt. Currently, there are 2 deposits with an issued exploitation concession located in the Dolnośląskie voivodeship (Jawor-Męcinka and Krzeniów), and 1 deposit located in the Podkarpackie voivodeship (Dylągówka-Zapady). Total domestic demand is covered by import.

11.3. Building ceramics raw materials

W. Szczygielski

Building ceramics products (so-called "red ceramics") are obtained from clayey raw materials via a production process consisting of 4 stages: raw material preparation, shaping of products from ceramic mass (usually by using the plastic forming method), drying, and firing in a temperature between 850 and 1,250°C. The following products are distinguished: construction (bricks, wall blocks, ceiling blocks, lintels, and ventilation blocks), roofing (tiles, ridge tiles), facing products (clinker bricks, tiles,

Table 11.3.1. Building ceramics raw materials resources [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**1,127**	**2,033.58**	**701.84**	**1,331.74**	**54.17**	**151.80**
Including resources of exploited deposits						
TOTAL	130	255.31	235.55	19.76	7.61	148.95
1. Deposits of operating mines	81	212.06	193.42	18.64	6.88	124.79
2. Deposits exploited temporarily	49	43.25	42.13	1.12	0.73	24.16
Including resources of non-exploited deposits						
TOTAL	301	1,443.81	179.59	1,264.22	23.22	–
1. Deposits covered by detailed exploration	227	230.27	179.59	50.68	12.62	–
2. Deposits covered by preliminary exploration	74	1,213.54	0.00	1,213.54	10.60	–
Including abandoned deposits						
Abandoned deposits	696	334.47	286.70	47.77	23.34	2.85

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

fittings), and other elements (drainage tubes, fencing products, etc.).

The main component of ceramic mass is clayey rock, which are characterized by an increasing plasticity when exposed to moisture. The production process can be carried out by using raw material exploited directly from a deposit; however the processing of raw material improves its characteristics. Initial preparation includes: preliminary crushing and mixing, moisturizing and seasoning on dumps or in storages. It aims to achieve the structure of a loose loam, to average and unify the material and to improve ceramic parameters. Technological additives are minor components in ceramic mass – used depending on the composition and properties of the main raw material, and on production process requirements, e.g.: to lower drying and firing shrinkage of products, to increase thermal insulation of products, and to decrease their mass through ceramic material porisation, reducing the sintering temperature, improving resilience and frost resistance. Some of these components are energy carriers and can replace a part of the fuel needed for the firing process. Natural raw materials are used as technological additives, e.g. quartz sand, waste raw materials: wood shavings, clayey-schists exposed to coal wastes, by-products of coal burning (silts, ashes, slags), rocky powders, waste from the paper industry and others. Using secondary (waste) raw materials in the production process is beneficial when considering environmental protection.

Raw materials used for building ceramics commonly occur in the whole country, however their distribution is uneven. The southern part of Poland is characterized by larger resources than other areas of the country (Plate 5). The raw materials occurring in this region are also more diverse and can be used in a number of ways. Clayey raw materials vary in terms of their origin and age. Currently, the Quaternary, Neogene, Jurassic and Triassic deposits are considered to be most important. The most important raw materials are:

- the Quaternary stagnant lake sediments, such as muds and clays occurring mainly in northern and central Poland;
- the Neogene clays, within the so-called Poznań series, from south-western and central Poland, and marine clays and muds occurring in south-eastern Poland (in the area of the Carpathian Foredeep);
- the Jurassic marine clays and muds occurring at the margin of the Holy Cross Mts., in the vicinities of

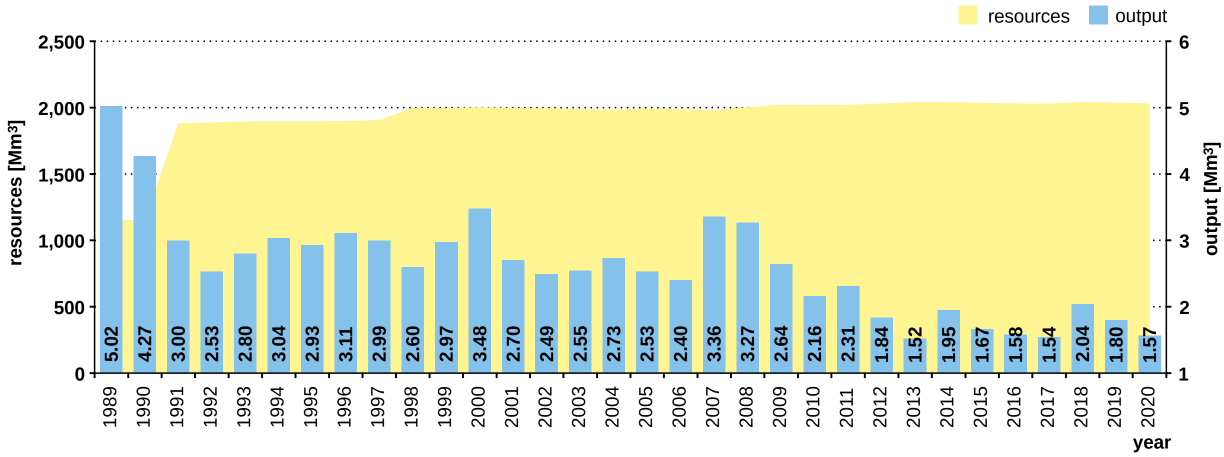


Figure 11.3.1. Building ceramics raw materials anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Częstochowa and Opole (the Silesia-Cracow Monocline);

- the Triassic clays, claystones and mudstones, occurring in the region of the Holy Cross Mts., in the vicinities of Częstochowa and the region of Upper Silesia.

For building ceramics production there are also alluvial loams, loesses, glacial loams and the Permian clays used. In the last 5 years shares of particular types in domestic output were as follows: the Neogene Poznań clays – 30.8%, marine clays of the Carpathian Foredeep – 30.8%, the Jurassic clays – 12.6%, the Quaternary stagnant clays and muds – 11.5%, the Triassic minerals – 10.4%, others – 3.9%. Currently, there are such unused sediments as the Oligocene septarian clays, occurring in the vicinity of Szczecin, clayey flysch sediments in the Carpathians, and the Carboniferous clayey-schists from the region of Upper Silesia.

According to the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987) the parameter limits that define a building ceramics raw material deposit and its boundaries (Appendix 8 – table 42) are:

- maximum documentation depth – to the depth of possible exploitation;
- minimum thickness of the deposit – 2 m;
- maximum overburden/thickness ratio – 0.5;
- maximum content of grains bigger than 2 mm – 1%;
- maximum content of ceramic marl in grains with a diameter bigger than 0.5 mm – 0.4%;
- minimum shrinkage in drying – 6%.

Anticipated economic resources of building ceramics raw material deposits, as of the end of 2020, amounted to 2,033.58 Mm³ (about 4,067.16 Mt) (Tab. 11.3.1).

In 2016–2020, there were 11 new deposits documented (excluding areas allocated from deposit which had been documented earlier). It resulted in the growth of anticipated economic resources by 14.462 Mm³, whereas anticipated sub-economic resources increased by 0.533 Mm³. The overall balance of resources, taking into account the growths and drops due to deposits boundaries changes, resources corrections and exploitation losses, is estimated at –10,758 Mm³.

The average annual output over the same period amounted to 1.706 Mm³/yr (ranging from 1.544 to 2.042 Mm³/yr) (Fig. 11.3.1). Exploitation levels fluctuated significantly – even by about 30–40%. In general, in the past several dozen years output has been characterized by a declining tendency. Current output is half the size it was 20 years ago. At the same time, the number of mines exploiting raw materials is decreasing: in 2020, there were 81 mines, in 2016 – 107, whereas 20 years ago the number was as high as 330. This was the result of changes in the technological progress of building ceramics production and in the construction sector, together with the modernization of ceramic industry in Poland and concentration of production in modern, automated plants. Decreasing output is also caused by increasing transport distance (and therefore the transport becomes less viable). Older brick factories, usually small ones, are being successively closing down.

In the last 5 years, the greatest output was recorded in the Świętokrzyskie voivodeship – 0.313 Mm^3 on average (18.3% of domestic output). Subsequent positions are occupied by voivodeships of the southern part of Poland: Śląskie – 0.202 Mm^3 (11.8%), Dolnośląskie – 0.186 Mm^3 (10.9%), Małopolskie – 0.178 Mm^3 (10.5%), Podkarpackie – 0.152 Mm^3 (8.9%), Opolskie – 0.125 Mm^3 (7.3%) – in total accounting for 49.4% of domestic output. The remaining 10 voivodeships account for 32.3% of domestic output: Mazowieckie – 0.124 Mm^3 (7.2%), Pomorskie – 0.123 Mm^3 (7.2%), Wielkopolskie – 0.086 Mm^3 (5.05%), Lubelskie – 0.066 Mm^3 (3.9%), Lubuskie – 0.047 Mm^3 (2.8%), Łódzkie – 0.031 Mm^3 (1.8%), Zachodniopomorskie – 0.025 Mm^3 (1.5%), Kujawsko-Pomorskie – 0.022 Mm^3 (1.3%), Podlaskie – 0.018 Mm^3 (1.1%), Warmińsko-Mazurskie – 0.008 Mm^3 (0.5%).

In the latest edition of "The balance of prospective mineral resources of Poland" (Szamałek *et al.*, eds., 2020), prognostic resources (category D_1) of building ceramics raw materials were assessed at 1,328 bnm^3 in 65 areas with a total area of 6,270 ha. Moreover, there were 267 prospective areas described (category D_2 without a resources assessment) with a total area of 26,172 ha (Szczygielski, Walentek, 2020). The majority of the prognostic resources are composed of Neogene clays of the Poznań series (45.7% of the prognostic resources, of which 20% are clays within brown coal deposits – an accompanying raw material), Miocene marine clays (33.3%), stagnant clays (18.3%) and others (2.7%). The geographical distribution of the prognostic resources is uneven: the Dolnośląskie voivodeship contains 43.1% of resources, the Podkarpackie voivodeship – 28.2%, the Podlaskie voivodeship – 9.2%, the Warmińsko-Mazurskie voivodeship – 5.1%, the Śląskie, Pomorskie, Świętokrzyskie and Małopolskie voivodeships – from 2 to 3% each, and in the remaining voivodeships – 6.2% in total. Except for the already designated areas, there are also other possibilities for the discovery of valuable clayey raw materials.

11.4. Calcite

D. Brzeziński

Veins of crystallized calcite, genetically originated from ascending hydrothermal processes, occur within the Devonian limestones and dolomites in the area of the Holy Cross Mts., and within the Carboniferous limestones in the vicinity of Cracow. Calcite is used in the ceramic industry as an additive, however lately it has been replaced by other high-calcium raw materials. In the past, it was used by the glass industry, or as a decorative stone for sacral buildings, as well as a compound in precious grits. The anticipated economic resources of vein calcite important to the industry were estimated at 233 kt, as of the end of 2020 (Tab. 11.4.1), and have not changed since 2012, when the Korzecko deposit was removed from "The balance…". In the Radomice I deposit calcite occurs as the main raw material, in 2 other deposits – Polichno-Skiby and Skrzelczyce – calcite is an accompanying raw material within limestone purposed for the construction and road infrastructure industries. For more than 30 years no calcite deposit in Poland has been exploited – mainly due to economic and environmental protection reasons.

Table 11.4.1. Calcite resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**3**	**0.23**	**0.23**	–	–	–
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	3	0.23	0.23	–	–	–

11.5. Ceramic clays

M. Tymiński

Ceramic clays are generally represented by sedimentary clays of a marine or lacustrine origin and with kaolinite and illite group minerals as major rock-forming components. The clays, also known as kaolin rocks, are raw materials for production of whiteware ceramics. From a processing standpoint, fired products may be assigned to whiteware or stoneware. For porcelite and faiance production, the used whiteware ceramic clays characterized by:

- 60% of whiteness when fired at a temperature of 1,200°C;
- a high bending (flexural) strength after drying – minimum of 0.6 MPa.

In turn, stoneware ceramic clays are characterized by a lesser degree of whiteness, but they possess high bending strength, large mechanical and chemical resistance, and a low level of water absorption after firing – maximum of 5%.

Whiteware ceramic clay deposits occur only in the Dolnośląskie voivodeship (Plate 7). There are 2 types of deposits. The first type is the Upper Cretaceous kaolinite clays forming interlayers in sandstone, represented by the Bolko II and Ocice deposits. The second type is the poorly cemented sandstones with kaolinite binder, and is represented by the Janina I, Janina-Zachód and Nowe Jaroszowice deposits. The usable fraction is separated from these rocks by water-washing and the obtained concentrate contains about 30% of kaolinite clay.

Stoneware ceramic clay deposits occur mainly in the Lower Silesia region and central parts of the country (Świętokrzyskie and Dolnośląskie voivodeships). Couple of deposits are located in the Mazowieckie voivodeship, while single deposits exist in the Łódzkie and Śląskie voivodeships (Plate 7).

In the latest edition of "The balance of prospective mineral resources of Poland", the assessment of prospective ceramic clay resources in Poland was updated (Galos, 2020b). Main criteria which were adopted for determining whiteware and stoneware ceramic clay deposits are: deposit thickness (minimum of 2 m), and overburden to a deposit thickness ratio (N/Z maximum of 2). In addition raw material qualitative parameters were adopted: clayey mineral content (minimum of 40%), $CaCO_3$ content (maximum of 2%) and grain content >2 mm (maximum of 1%). Taking into account also such parameters as whiteness after firing, bending (flexural) strength or water absorption after firing, the prognostic resources of whiteware and stoneware ceramic clays were assessed at 127.20 Mt (within 3 areas in the Dolnośląskie voivodeship) and 230.41 Mt (within 9 areas: 2 in the Świętokrzyskie voivodeship and 7 in the Dolnośląskie voivodeship), respectively.

As of end of 2020, anticipated economic resources of whiteware ceramic clays amounted to 60.39 Mt (Tab. 11.5.1) and decreased by 0.17 Mt (it means by 0.28%) in comparison to the previous year. The decrease was a result of exploitation and losses. Similar to previous years, the Janina I deposit was the only whiteware ceramic clays deposit exploited in Poland – output amounted to 161.92 kt of sandstones cemented with kaolinite binder, which is 40.77 kt less than in 2019 (decrease by 20.11%). Economic resources of the raw material, as of end of 2020, were estimated at 0.73 Mt and decreased by 0.17 Mt in comparison to the previous year – due to exploitation and losses.

As of the end of 2020, anticipated economic resources of stoneware ceramic clays amounted to 77.79 Mt and decreased in comparison to the previous year by 0.96 Mt (1.22%). The decrease in resources resulted from:

- removing 2 deposits from "The balance…": Borkowice II (–0.56 Mt) and Borkowice-Radestów 1 (–0.04 Mt);
- exploitation and losses.

The anticipated economic resources within exploited deposits amounted to 7.10 Mt, which accounted for 9.13% of total anticipated economic resources. Almost all of these resources were covered by detailed exploration (A+B, C_1 categories). Only in the Baranów deposit 3 kt of resources explored in a C_2 category remained. Economic resources decreased by 0.90 Mt (21.58%) as a result of removing the Borkowice II deposit from "The balance…" (–0.56 Mt), and exploitation and losses. The economic resources amounted to 3.27 Mt and accounted for 46.06% of the anticipated economic resources of the exploited deposits (Tab. 11.5.2). In 2020, exploitation of stoneware ceramic clays was carried out in 3 deposits. Total output amounted to 229.24 kt and decreased by

Table 11.5.1. Whiteware ceramic clays resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**5**	**60.39**	**4.45**	**55.94**	**0.05**	**0.73**
Including resources of exploited deposits						
Deposits of operating mines	1	3.73	3.69	0.05	–	0.73
Including resources of non-exploited deposits						
TOTAL	3	56.25	0.36	55.89	–	–
1. Deposits covered by detailed exploration	1	0.36	0.36	–	–	–
2. Deposits covered by preliminary exploration	2	55.89	0.00	55.89	–	–
Including abandoned deposits						
Abandoned deposits	1	0.40	0.40	–	0.05	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

Table 11.5.2. Stoneware ceramic clays resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**19**	**77.79**	**30.13**	**47.66**	**15.19**	**3.27**
Including resources of exploited deposits						
Deposits of operating mines	3	7.10	7.10	0.00	5.10	3.27
Including resources of non-exploited deposits						
TOTAL	10	57.52	11.79	45.73	8.40	–
1. Deposits covered by detailed exploration	6	15.03	11.79	3.25	2.30	–
2. Deposits covered by preliminary exploration	4	42.48	0.00	42.48	6.11	–
Including abandoned deposits						
Abandoned deposits	6	13.17	11.24	1.93	1.69	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

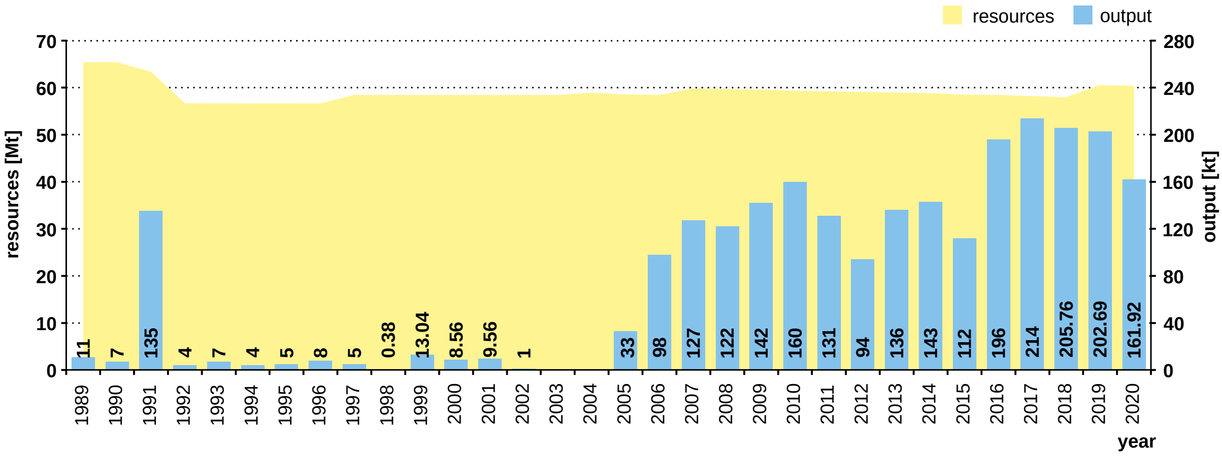


Figure 11.5.1. Whiteware ceramic clays anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

11.22% (28.96 kt) in comparison to 2019. A significant output increase was recorded in the Zebrzydowa Zachód deposit (by 13.80 kt, that is by 7.42%), whereas there a slight growth was noted in the Baranów deposit (by 0.04 kt, that is 0.30%). The rate of exploitation in the Rozwady 1 deposit decreased by 4.80 kt (23.08%), and amounted to 16 kt. The negative balance of output was also caused by removing the Borkowice-Radestów 1 deposit from "The balance…" – the output from this deposit was estimated at 38 kt in 2019.

Anticipated economic resources of whiteware ceramic clays remained, in the period presented in Figure 11.5.1, in the range between 65.42 and 56.66 Mt. Taking the 1989–2015 period into consideration, the most significant resources decrease was recorded in 1992 as the result of removing the Turów deposit from "The balance…" (–6.70 Mt). On the other hand, the visible increases of resources took place in 1997 (by 1.81 Mt – due to the reclassification of resources in the Anna-Włodzice Małe, Ocice and Ocice II deposits), and in 2007 (by 1.37 Mt – as a result of additional resources being documented in the Janina I deposit). Other years were characterized by the stability of resources, with slight changes resulting from the exploitation and better exploration of deposits. In 2015, the Janina deposit was removed from "The balance…". Between 2016–2020, resources remained at 57.98–60.56 Mt. Between 2016–2018 and in 2020, slight decreases in whiteware ceramic clay resources were caused by the exploitation and better exploration of the Janina I deposit, whereas a growth in 2019 was the result of new documentation, with recalculated resources, elaborated for the Janina I deposit (+2.78 Mt) and the Janina-Zachód deposit (–0.20 Mt).

Output of the given raw material was changing significantly over the presented period. Generally, the clays were not a subject of intensive exploitation until 2004 – as they were only obtained as an accompanying raw material in the course of brown coal production. An exception occurred in 1991, when there were 135 kt of raw material exploited. Increases in output started to be recorded as early as in 2005, when exploitation of the Janina I deposit began. Until 2010 output increased to 160 kt and fluctuated significantly in the following 5 year. The output of whiteware ceramic clays (from the only exploited deposit – Janina I) significantly increased from 2016–2017 to 214 kt (the highest amount in the whole presented period) and then decreased to 162 kt in 2020.

Figure 11.5.2 presents changes in anticipated economic resources and output of stoneware ceramic clays from 1989 to 2020. Variations in production were much more significant than in the case of whiteware ceramic clays. The resources varied between 76.29 Mt (in 2016) and 105.32 Mt (in 1996). The biggest resources increases were recorded in 1991 (by 20.32 Mt – due to the documentation of a new deposit – Chełsty), in 1996 (by 8.46 Mt – due to the documentation of a new deposit – Wierzbka) and in 2005 (by 4.83 Mt – due to the documentation of a new deposit – Zebrzydowa Zachód). The most significant decrease in resources took place in 1997 (by 23.72 Mt – as the result of new documentation with recalculated resources approved for the Chełsty deposit).

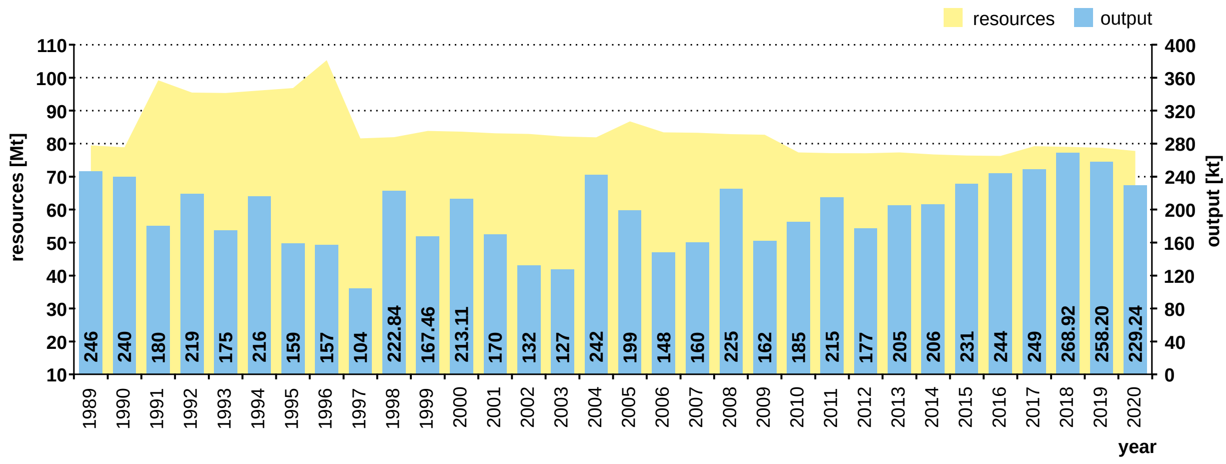


Figure 11.5.2. Stoneware ceramic clays anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Decreases in 1992, 2006 and 2010 were recorded due to: better exploration and reassessment of the Majków deposit; reclassification of raw material in the Gozdnica deposit, and removal of the Kaławsk-Południe deposit from “The balance…”, respectively. Other resource changes were mainly the result of exploitation, losses and deposit exploration. Only in 2015 the resources decreased (by 0.34 Mt) as the result of removing 5 deposits from “The balance…” (Barbara Sadlno, Gierałtów, Kleszczowa, Nowogrodziec II and Zebrzydowa). Considering the last 5 years, the anticipated economic resources have not changed significantly and amounting to between 76.29 and 79.23 Mt. The resources increased once again in 2017, due to new documentation being elaborated, which contained recalculated resources for the Zebrzydowa Zachód deposit (+2.95 Mt). In the remaining years, the resources decreased due to exploitation and losses. Nevertheless, it should be noted that there were 2 new raw material deposits documented over said period: the Rozwady 1 deposit in 2016 (+0.13 Mt), and the Borkowice-Radestów 1 deposit in 2018 (+0.08 Mt). In 2020, 2 deposits were removed from “The balance…” – Borkowice II (–0.56 Mt) and Borkowice-Radestów 1 (–0.04 Mt).

Output of the given raw material varied over the whole presented period between 104 and 269 kt. A decreasing trend was observed up to 1997, while in the next 15 years output displayed some fluctuations. The biggest exploitation increases were recorded in 1998 and 2004 – by 118.84 kt (more than twofold) and 115 kt, respectively. In 1998, there was more intensive exploitation taking place in the Kraniec and Gozdnica II deposits, whereas in 2004 a significant increase in output was recorded in the Zebrzydowa deposit, together with increases from other exploited deposits. Regarding the 2016–2020 period, output was systematically increasing in 2016–2018 – to 269 kt, and then decreased in the following two years to 229 kt. The Zebrzydowa Zachód deposit remains as being the most important deposit in Poland, due to its raw material output – in 2020, its contribution represented 87.14% of total output. The Rozwady 1 and Baranów deposits were of minor importance.

11.6. Chalk

W. Szczygielski

Chalk is a calcareous, soft and porous sedimentary rock characterized by a high calcium carbonate ($CaCO_3$) content and a very fine-grained structure. It is used mainly in:

- rubber, paper, chemical, pharmaceutical, cosmetic, ceramic and cement industries;
- for production of paints and lacquers, plastic, building materials;
- in agriculture as fertilizer chalk for soil liming and as fodder chalk for the animals breeding.

This natural raw material is being increasingly replaced by lime meals doping from the processing of limestones and marbles, and by a raw material gained from the process of solutions precipitation.

In Poland, chalk is a name traditionally given to 2 different mineral raw materials: proper chalk rock (still often referred to as "writing chalk" in Polish literature) and lacustrine chalk (calcareous tufa). The raw materials differ in origin, chemical composition and use.

The proper chalk is an organogenic marine sediment of a white or creamy color composed mainly of planktonic organism remains: coccoliths and foraminifera crusts. In Poland, chalk occurs in the Cretaceous sediments in the Lublin area and in the area of north-eastern Poland, where the Cretaceous deposits occur in the form of ice floats within the Quaternary sediments (Plate 6). In the vicinity of Kornica and Mielnik, on the Bug river border of the Mazowieckie and Podlaskie voivodeships, there have been 22 deposits of "writing chalk" documented, and 1 deposit in the Pomorskie voivodeship. In the Lublin area, in the vicinity of Chełm "writing chalk" is exploited for cement production. The deposits occurring in this region are presented in the Chapter 11.18.

The lacustrine chalk usually has a white, white-yellow or grey color and is a very damp, clammy mass. It originates from biochemical precipitation and accumulation of carbonate sediment on lake bottoms. Plants play a significant role in this process by absorbing dissolved calcium dioxide (CO_2) from water. This results in changes in solution saturation, causing calcite crystallization. With the exception of carbonates, lacustrine sediments contain organic matter and terrigenous material. Lacustrine chalk usually contains a minimum calcium carbonate ($CaCO_3$) of 80%, whereas the sediments with a calcium carbonate content between 50 and 80% is called calcareous gyttja. Very often the lacustrine chalk and gyttja beds occur below peat beds, which is the result of shallowing and encroachment of a sedimentary reservoir (lake). Considering the above, the two are documented collectively. The lacustrine chalk deposits in Poland are usually Quaternary in age, and occur mainly in northern and north-western Poland. The Neogene chalk accumulations are known to be located in the vicinity of Bełchatów in central Poland, where they occur within the overburden of exploited brown coal beds.

According to the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987) the parameter limits that define a deposit and its boundaries (Appendix 8) are:

- lacustrine chalk and calcareous gyttja (table 38) are documented with minimum deposit thickness of 1 m, maximum ratio of overburden to deposit thickness of 0.3, and minimum alkalinity expressed per unit of CaO in dry mass of 40% (that means 71.2% of $CaCO_3$);
- proper "writing" chalk (table 39) is being documented to a maximum depth of 70 m, with a maximum overburden of 15 m, a maximum ratio of overburden to deposit thickness of 0.2 and a minimum weighted average of $CaCO_3$ content in a deposit profile of 80% (that means 44.8% of $CaCO_3$).

In 2020, total anticipated economic resources of chalk and calcareous gyttja amounted to 206.617 Mt (Tab. 11.6.1), including 36.010 Mt (17.4% of the total resources) of proper ("writing") chalk and 170.607 Mt (82.6%) of lacustrine chalk and calcareous gyttja.

In the 2016–2020 period, the number of deposits increased by 9, including: 2 deposits of proper chalk and 7 deposits of lacustrine chalk or calcareous gyttja. The increase in anticipated economic resources was estimated at about 5,379 kt, including: 1,476 kt of proper chalk, and 3,903 kt of lacustrine chalk and calcareous gyttja. The balance of resources resulting from deposit boundary changes, resource corrections, and exploitation losses was estimated at 2,476 kt.

During the aforementioned period, average annual output amounted to 242 kt of chalk (varying between 175 and 310 kt), including: 216 kt (163–270 kt) of proper chalk – 89.3%, and 26 kt (12–40 kt) of lacustrine chalk – 10.7%. There were between 11 and 13 chalk deposits being exploited, of which 8–10 proper chalk deposits (9 located in the Mazowieckie voivodeship and 1 located in the Podlaskie voivodeship) and 2–4 lacustrine chalk deposits (1 located in the Pomorskie voivodeship and 3 located in the Zachodniopomorskie voivodeship). The annual output has increased significantly. The volume of output increased from just a couple percent in 2016 to 46% in 2018. Only in 2020 a decrease in exploitation was recorded – by 23.1%, as a result of the COVID-19 pandemic. The increase in output applied to both, proper chalk and lacustrine chalk. Over the last 5 years increased exploitation from 20 kt/yr to more than 30 kt/yr, mainly due to the new Lubiatowo IV mine coming into operation.

Table 11.6.1. Chalk resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**199**	**206.62**	**109.69**	**96.93**	**15.47**	**12.92**
Including resources of exploited deposits						
TOTAL	14	15.88	15.42	0.46	–	12.68
1. Deposits of operating mines	12	15.59	15.13	0.46	–	12.64
2. Deposits exploited temporarily	2	0.29	0.29	–	–	0.04
Including resources of non-exploited deposits						
TOTAL	93	134.46	58.43	76.03	3.24	–
1. Deposits covered by detailed exploration	59	73.49	58.43	15.06	0.55	–
2. Deposits covered by preliminary exploration	34	60.97	0.00	60.97	2.69	–
Including abandoned deposits						
Abandoned deposits	92	56.28	35.84	20.44	12.23	0.23

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

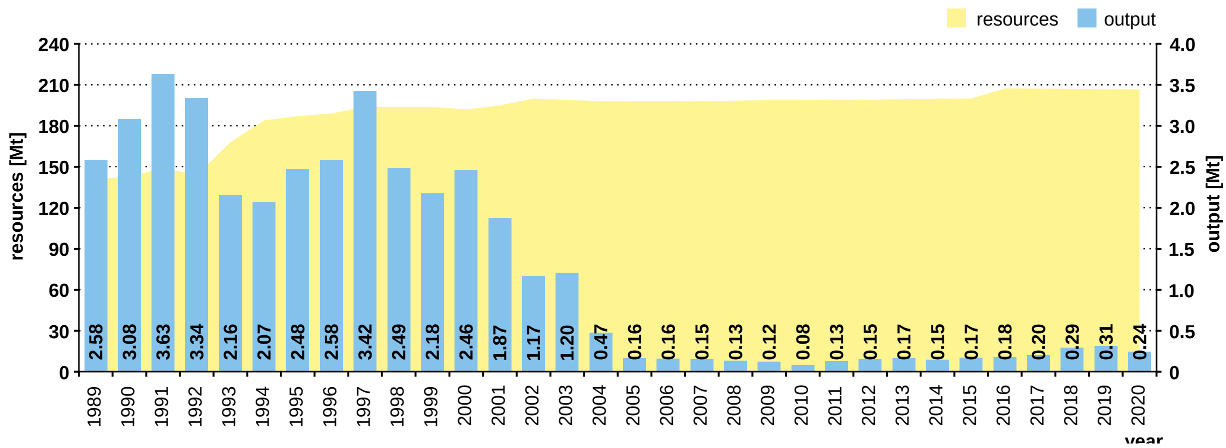


Figure 11.6.1. Chalk anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Lacustrine chalk can also be temporarily recovered from the overburden of brown coal beds in the vicinity of Bełchatów. In the 2016–2020 period, there were 138 kt (11–50 kt per year) of lacustrine chalk exploited from the Bełchatów-pole Szczerców deposit. This amount was not included in the provided volume of output (and in the graph – Fig. 11.6.1) due to formal reasons.

Most of the chalk and calcareous gyttja deposits are located within the lakeland areas of the Wielkopolska region, the Lubusz Land, and the Pomerania, Masuria, Warmia and the Suwalszczyzna regions. These are also the prospective areas for raw material occurrences (Jurys, 2020).

11.7. Clay raw materials for cement production

W. Szczygielski

In the cement industry clay raw materials are used for clinker cement firing and to obtain additives for cement (and concrete). In clinker production natural clayey raw materials (loam, clay, clayey schist, loess and others) are used as a compound amending or complementing basic raw material – that is carbonate rock, limestone and marl. A mixture prepared for firing should be characterized by appropriate proportions of the main compounds such as CaO, SiO_2, Al_2O_3 and Fe_2O_3 and low contents of damaging compounds. Optimum $CaCO_3$ content in the raw material purposed for clinker baking is 75–80% (42–45% of CaO). When composition of a basic raw material is too high, various mineral additions are used e.g. clayey raw materials providing SiO_2, Al_2O_3 and Fe_2O_3. Proportions of main compounds in the raw material are characterized by:

- hydraulic modulus MH = $CaO/(SiO_2+Al_2O_3+Fe_2O_3)$,
- silica modulus MK = $SiO_2/(Al_2O_3+Fe_2O_3)$,
- aluminous modulus MG = Al_2O_3/Fe_2O_3.

In the case of Portland clinker production these values should be within the following ranges: MH 1.9–2.9; MK 2.1–3.5; MG 1.0–2.8.

For cement production (from clinker) there can be clayey raw materials after thermal treatment used, which after grinding show pozzolana properties and can be used as a substitute for cement clinker. Materials of this type are e.g. fired coal schist or heated kaolin loam (metakaolinite). Pozzolana additives lowers costs of cement production (mainly energy consumption) and have a positive impact on cement and concrete properties. Their acceptable content in cement is 55%.

The GML does not specify the parameter limits that define a deposit of this raw material – it is not listed in the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987). Decisive are the needs and requirements of the recipient of the raw material, which are adjusted within the range of its type and composition. In cement, the contents of MgO, P_2O_5 and Mn_2O_3, and the high content of SO_3 and NaO and K_2O alkalies are undesirable, therefore their raw material content should be as small as possible. Other important factors include a small distance from a deposit to a processing plant, and favorable exploitation conditions.

Clayey rocks, potentially usable, occur within significant areas in Poland and are easily accessible. Documented deposits and identified prognostic and prospective areas contain lithologically varied geological formations – from the Quaternary up to the Cambrian.

In Poland, there are 13 cement plants operating at the moment, of which 2 concentrate on clinker grinding (in 2019 production in the "Rejowiec" cement plant was stopped). Production of cement clinker in 2016–2020 amounted to 13,566 kt annually (12,075–14,361 kt), cement production amounted to 19,788 kt on average (15,782–19,049 kt), including Portland cement producing on average 15,747 kt (13,835–16,675 kt).

Anticipated economic resources of deposits amount to 279.52 Mt (Tab. 11.7.1). There was an increase in resources recorded, by about 3.7 Mt (1.3%), as the result of geological-documentation work and the reclassification of resources in the Lubelskie voivodeship.

Exploitation was carried out from 3 deposits of loam and silt in the Lubelskie voivodeship, for purposes of the "Chełm" cement plant. In the 2016–2020 period, the exploitation amounted to 97 kt on average (57–165 kt).

Raw materials are also obtained **from other sources:** sand and clayey raw materials obtained from deposits classified for cement production (partial data), but mainly waste raw materials were used i.a.: metallurgical slags, secondary products of coal combustion, coal schist and others (Tab. 11.7.2).

Table 11.7.1. Resources of clay raw materials for cement production [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**26**	**279.52**	**169.69**	**109.82**	**45.63**	**2.48**
Including resources of exploited deposits						
Deposits of operating mines	2	3.31	3.31	–	–	2.07
Including resources of non-exploited deposits						
TOTAL	17	201.68	92.02	109.65	2.25	–
1. Deposits covered by detailed exploration	15	95.40	92.02	3.37	2.25	–
2. Deposits covered by preliminary exploration	2	106.28	0.00	106.28	–	–
Including abandoned deposits						
Abandoned deposits	7	74.53	74.36	0.17	43.39	0.41

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

Table 11.7.2. Supplementary and corrective raw materials used for cement production [kt]

Raw material origin	2016	2017	2018	2019	2020	Average
Primary raw materials						
IC	6	0	114	165	92	75.4
PC	50	69	143	0	65	65.4
IB	52	57	–	–	–	54.0
Others	lack of data	lack of data	lack of data	lack of data	lack of data	lack of data
TOTAL	**108**	**126**	**258**	**165**	**157**	**163.0**
Secondary raw materials						
Mining and industrial wastes (excluding alternative fuels)	about 4,500 kt per year					

IC – deposits of clay raw materials for cement production, PC – deposits of quartz sand for production of silicate brick and cellular concrete, IB – deposits of building ceramics raw materials

Prognostic and prospective areas of deposit occurrence:

- prognostic resources (D_1 category) in 1 area located in the Świętokrzyskie voivodeship (2 ha), with resources amounting to 77 kt;
- 10 prospective areas (D_2 category) with their total size of 2,466 ha (2 areas in the Pomorskie voivodeship – 49 ha, 1 area in the Podkarpackie voivodeship – 68 ha, 7 areas in the Świętokrzyskie voivodeship – 2,349 ha) (Szczygielski, Walentek, 2020).

Clay raw materials for cement production anticipated economic resources and output in 1989–2020 is presented in Figure 11.7.1.

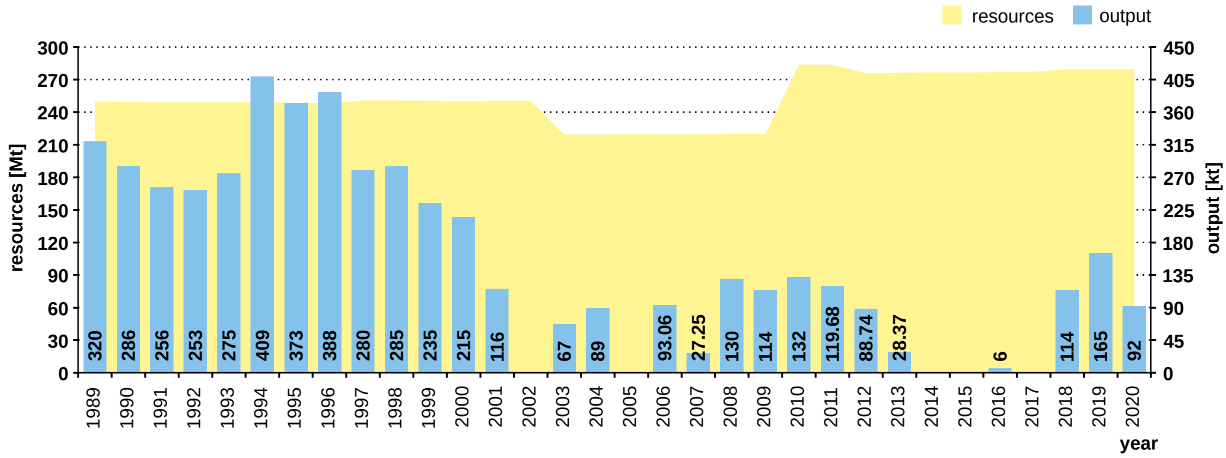


Figure 11.7.1. Clay raw materials for cement production anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

11.8. Clay raw materials for lightweight aggregate production

W. Szczygielski

In Poland, the occurrence of clay raw materials for the production of lightweight aggregates may be assigned to 2 major types in relation to their utility: raw materials suitable for the production of ceramsite (in Poland referred to as "gliniec"), and raw materials suitable for the production of agloporite (in Poland referred to as "glinoporyt"). Ceramsite and agloporite are artificial lightweight aggregates obtained as the result of thermal treatment (firing) of clay raw materials.

The raw materials used in the ceramsite production are characterized by an expansion during their thermal treatment. The coefficient (the quotient of clay volume in a swollen state and clay volume after production) characterizing that property, that is the swelling coefficient, should be equal at least 2.5 and preferably 5.0 and more. To increase the swelling of raw material there are technological additives used, such as: brown coal, diesel oil, alkalis. The process of ceramsite production involves roasting of an appropriately prepared and granulated clay raw material in temperatures between 1,050 and 1,300°C. In the course of roasting, granules increase their volume due to the gases emanating in the soft pyroclastic mass and their external layer begins to melt forming a parched shard. The obtained porous, light-weight ceramic aggregate is characterized by low soakability, high thermo-insulating properties and a high resistance to several chemical agents. Usually, the raw material for the production of ceramsite can also be used in the production of building ceramic wares: bricks, ceramic concretes, etc. In this case, the roasting process is being carried out in lower temperatures, than during the production of ceramsite, meaning below the swelling coefficient for particular raw materials.

The ceramsite is used mainly in the building industry for the production of concrete, construction elements, and as an insulating and drainage material. It is also used in road construction, horticulture, and agriculture.

The raw materials used for agloporite production do not expand in the course of the thermal treatment, as their swelling coefficient does not exceed 1.0. The process of agloporite production involves the roasting of a granulated mixture of clayey raw material and easily combustible particles. As a result of roasting, the combustible particles make the end-product material highly porous. The obtained sintered granules are subsequently crushed, which makes it possible to obtain aggregates characterized by high open porosity and a relatively low density. In Poland, agloporite was produced in the 1970s in 6 plants, from alluvial, glacial loams and the Pliocene clays. Such aggregates were mainly used by building industry for the production of light concretes, concrete blocks, and hollow bricks. This production was abandoned due to high energy consumption and a low quality of the obtained end-product material.

The so-called "fired shales" represent a material close to agloporite. It is also being called "shale-porite". This raw material occurs as the result of spontaneous fires of coal-waste stockpiles produced from hard coal mining operations. The fires turn clay-shales, which form a large part of the coal waste stockpiles, into a strong ceramic material. "Fired shales" are available on the Polish market as aggregates, utilized for building and road construction. They are treated as a reusable product made from waste material and thus data on their resources and supplies are omitted in "The balance…".

In Poland, deposits of raw materials useful for ceramsite production are limited in number, as only a few varieties of clay are characterized by a sufficient ability to swell during thermal treatment. There have been 8 deposits documented so far, which represent various geological formations: the Quarternary ice-dammed clays (Gniew II, Nawra), lacustrine Pliocene clays (Budy Mszczonowskie, Uniejów, Wierzchocin), referred to as "iły poznańskie" in Polish, marine Miocene clays (Ruda), Oligocene septarian clays (Bukowo – Szczecin-Płonia), and marine Dogger clays (Gołaszyn). Their average swelling coefficients are within a range of 2.5–5.5, with 4.2 being the average.

Clay raw materials (rocks), potentially useful in the production of agloporite, are fairly common throughout the entire country. Documented deposits of agloporite raw materials are represented by the Quaternary glacial loams and loesses (loess loams) and last, the Quaternary stagnant lake clays and the Neogene clays.

The GML does not define the parameter limits that define a raw material deposit – it is not listed in the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987).

The majority of geological documentation comes from the 1960–1980 period. Since 1970 the following balancing criteria came into force (only basic parameters):

- raw material for ceramsite production: minimum swelling coefficient in laboratory of 2.5 in natural state or after enrichment; minimum deposit thickness (Z) of 3.0 m; minimum overburden thickness (N) up to 6.0 m or more when swelling coefficient exceeds 5.5, overburden thickness to deposit thickness N/Z depending on swelling coefficient from 1.0 to 3.5 or more when swelling coefficient exceeds 5.5, maximum exploration depth to about 30 m;
- raw material for agloporite production: minimum fraction >2 mm content up to 3%, maximum marl grain content Ø >1 mm up to 1.0%, maximum total sulfur content per SO_3 up to 3.0%; geological-mining parameters: minimum deposit thickness of 3.0 m, maximum overburden thickness of 6.0 m, overburden thickness to deposit thickness N/Z ratio from 0.1 to 0.75 depending on the arbitrary bulk density of agloporite obtained in laboratory, maximum exploration depth up to about 30 m.

Anticipated economic resources as of the end of 2020, amounted to 167.856 Mm^3 (about 335.712 Mt) (Tab. 11.8.1) from which the resources for ceramsite production within 8 deposits amounted to 39.749 Mm^3 (about 79.498 Mt) – 23.7% of the total resources. Anticipated economic resources for agloporite production amounted to 128.107 Mm^3 (about 256.214 Mt) – 76.3% of the total resources.

There is only 1 deposit for ceramsite production being exploited – the Quaternary ice-dammed clays of the Gniew II deposit, located in the Pomorskie voivodeship. Exploitation and production is carried out by the Leca Polska Ltd. Company. In the 2016–2020 period, the output volume amounted to 0.104 Mm^3 on average (0.097–0.110 Mm^3). Earlier, there were also 2 ceramsite factories operating: until 1995 ceramsite was produced in the city of Szczecin (Zachodniopomorskie voivodeship) from the Oligocene septarian clays exploited from the Bukowo deposit (Szczecin-Płonia), and until 2015 in the town of Budy Mszczonowskie (Mazowieckie voivodeship) from Pliocene clays.

Changes in resources which have been recorded in recent years, were of minor importance and resulted from the Gniew II deposit exploitation and updating of resources within the abandoned Budy Mszczonowskie deposit.

Prognostic and prospective areas of deposit occurrences (Szczygielski, Walentek, 2020):

- raw material for ceramsite production: 5 prognostic areas (category D_1) with the total area size of 388 ha,

Table 11.8.1. Resources of clay raw materials for lightweight aggregate production [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**41**	**167.86**	**40.17**	**127.69**	**4.40**	**2.17**
Including resources of exploited deposits						
Deposits of operating mines	1	7.88	7.88	–	–	0.89
Including resources of non-exploited deposits						
TOTAL	37	149.55	21.86	127.69	3.32	–
1. Deposits covered by detailed exploration	9	26.89	21.86	5.02	0.06	–
2. Deposits covered by preliminary exploration	28	122.66	0.00	122.66	3.26	–
Including abandoned deposits						
Abandoned deposits	3	10.43	10.43	–	1.08	1.29

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

and resources amounted to 38.081 Mm^3, and 7 prospective areas (category D_2) with the total area size of 1,112 ha;

- raw material for agloporite production: 4 prognostic areas (category D_1) with the total area size of 235 ha and resources amounting to 12.138 Mm^3, and 11 prospective areas (category D_2) with the total area size of 964 ha.

Competitive to ceramsite and agloporite are perlitoporite and vermiculitoporite obtained from natural imported raw materials. Other materials are produced from waste raw materials or obtained as a by-product of: ash pore (e.g. Certyd), Gransil, Isopor, granulated slags, metallurgical pumice, products of coal combustion. Ceramsite is also being imported.

11.9. Dimension and crushed stone

D. Brzeziński, W. Miśkiewicz

A group of mineral raw minerals presented in “The balance...” as dimension and crushed stone (also referred to as road and building stones) comprises 33 lithological varieties of igneous, sedimentary and metamorphic rocks displaying specific properties which make them useful in the domestic market. Stones that meet relevant requirements are used to produce crushed aggregate – a high-grade raw material for building, road and railway construction and stone elements for road construction (stone for paving roads, stone and stone slabs for sidewalks, stone street curbing and curb ramps) and for building construction (stone blocks, decorative slabs for facade, floor slabs).

Igneous and metamorphic rocks exploited for dimension and crushed stone, mainly occur in southern Poland, within the areas of the voivodeships: Dolnośląskie (basalt, granite, granodiorite, syenite, diabase, gabbro, melaphyre, porphyry, porphyric tuff, amphibolite, serpentinite, greenstone, gneiss, migmatite, crystalline schist, marble), Opolskie (basalt, granite, gneiss and marble), and Małopolskie (diabase, melaphyre, porphyry

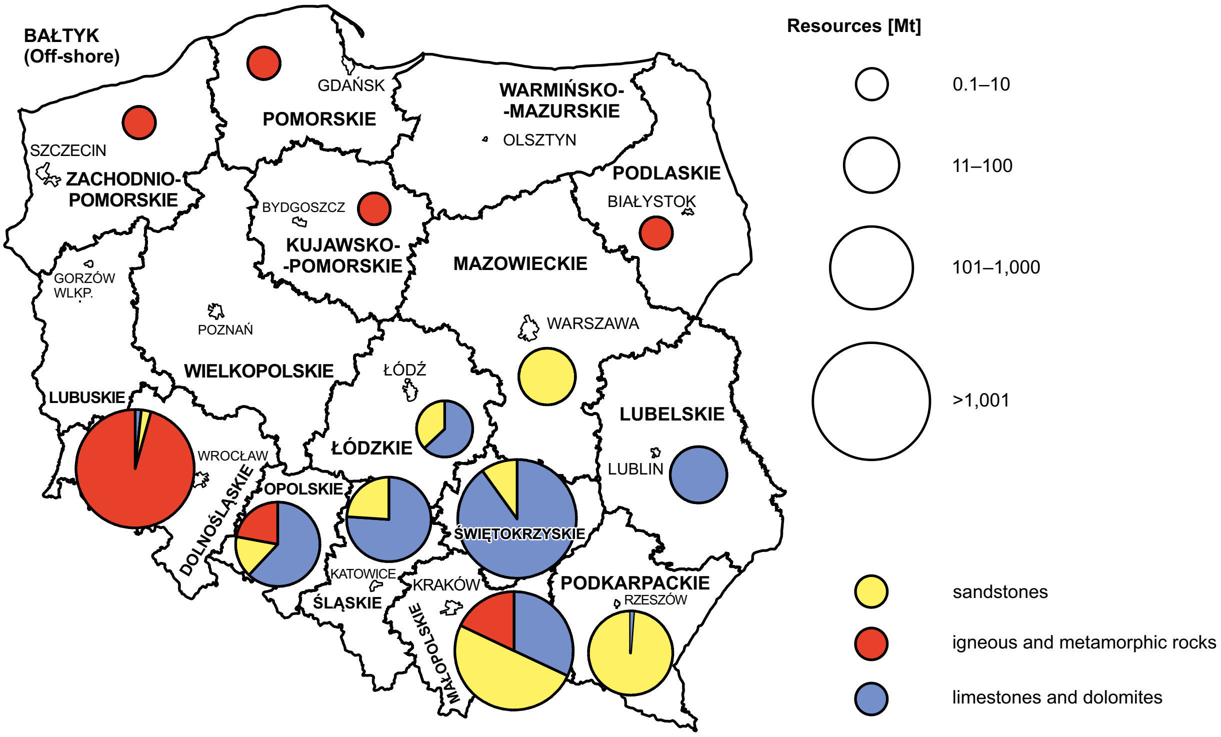


Figure 11.9.1. Distribution of resources and principal lithological types of dimension and crushed stone in Poland in 2020

and porphyric tuffs). Sedimentary rocks matching exploitation requirements are much more common. Limestone and dolomite form numerous deposits in the Dolnośląskie, Łódzkie, Małopolskie, Śląskie and Świętokrzyskie voivodeships; sandstone forms in the Dolnośląskie, Łódzkie, Małopolskie, Podkarpackie, Śląskie and Świętokrzyskie voivodeships, whereas limestone, opokas and marble in south-eastern Poland (Lubelskie and Podkarpackie voivodeships) (Fig. 11.9.1, Plate 6).

According to parameter limits that define a deposit and its boundaries, dimension and crushed stone are documented down to a depth where both, equipment and method, meet their detection limits for an opencast exploitation system. Additional requirements for dimension stone are:

- minimum overburden to deposit thickness ratio of 1.0;
- minimum divisibility for particular lithological types:
  - 5% for marbles and serpentinites;
  - 10% for syenites, gabbros, granodiorites and limestones, and limestone and dolomite prone to high-quality polishing;
  - 20% for granite, tuff, sandstone and limestone, and dolomite prone to high-quality polishing; in the case of non-block forming stone for building and road construction overburden may reach 15 m in thickness, with a maximum overburden to deposit thickness ratio of 0.3, a maximum contribution of rocks that do not meet the quality requirements in a given vertical section of a deposit of 20%, and a maximum $CaCO_3$ content in limestones of 90%.

Prospective resources of dimension and crushed stone were assessed at about 36,921 Mt, whereas the biggest resources are located in the area of the Małopolskie voivodeship (53.4% of total resources), the Świętokrzyskie voivodeship (16.4%), the Śląskie voivodeship (13.0%) and the Dolnośląskie voivodeship (10.7%) (Brzeziński, Miśkiewicz, 2020). Assessed prognostic resources of dimension and crushed stone amount to about 33,208 Mt, with their occurrence being concentrated in the Dolnośląskie voivodeship (82.3% of total resources) and the Śląskie voivodeship (13.4%). The prospective and prognostic resources are concentrated mainly within the area of 4 voivodeships: the Dolnośląskie, Małopolskie, Śląskie and Świętokrzyskie, which are the current mining centers of these raw materials from documented deposits. Considering the lithology, the largest resources are formed by sedimentary rocks (32,867 Mt of prospective resources and 5,845 Mt

Table 11.9.1. Dimension and crushed stone resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**741**	**11,521.44**	**8,276.09**	**3,245.35**	**528.03**	**3,679.11**
Including resources of exploited deposits						
TOTAL	316	6,213.74	5,181.14	1,032.60	96.98	3,549.45
1. Deposits of operating mines	229	5,534.80	4,594.55	940.25	94.31	3,181.84
2. Deposits exploited temporarily	87	678.94	586.59	92.35	2.67	367.62
Including resources of non-exploited deposits						
TOTAL	247	4,372.82	2,312.14	2,060.68	387.33	129.66
1. Deposits covered by detailed exploration	200	2,594.09	2,312.14	281.95	130.18	129.66
2. Deposits covered by preliminary exploration	47	1,778.73	0.00	1,778.73	257.15	–
Including abandoned deposits						
Abandoned deposits	178	934.87	782.80	152.07	43.72	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

of prognostic resources – these are mainly sandstone, limestone and dolomite), followed by metamorphic rocks (765 Mt of prospective resources and 23,905 Mt of prognostic resources – mainly gneiss), and then – igneous rocks (3,289 Mt of prospective resources and 3,458 Mt of prognostic resources – mainly granodiorite and granite).

As of the end of 2020, anticipated economic resources of dimension and crushed stone amounted to 11,521.44 Mt (Tab. 11.9.1). They decreased by 21.81 Mt, that is by 0.19% in comparison to the previous year. The number of deposits fell from 742 to 741 – 5 new deposits were documented, 3 deposits were removed from "The balance…" in 2019, and 3 deposits were reassigned as raw materials for the cement and lime industries. Sedimentary rock deposits are the most numerous, represented by 542 deposits, accounting for 69.7% of total deposits. There are 174 documented igneous rock deposits (accounting for 22.3% of total deposits), whereas the metamorphic rock deposits amount to 62 (8.0%). Sedimentary rock anticipated economic resources represent 47.8% of total resources (5,510.41 Mt), while igneous rocks represent 39.6% (4,564.10 Mt) and metamorphic rocks represent 12.6% (1,446.93 Mt). In comparison with the previous year, the most significant growth in resources was recorded for igneous rocks, by 77.50 Mt (or by 1.73%) – mainly due to increases in granite and porphyry resources. The resources of sedimentary and metamorphic rocks decreased by 92.04 Mt (1.64%) and by 7.27 Mt (0.50%), respectively. About 53.9% of the anticipated economic resources of the discussed group of raw materials, i.e. 6,213.74 Mt, include 316 deposits, which were exploited continuously or temporarily). Within the group of non-exploited deposits there are 200 deposits covered by detailed exploration, with the resources estimated at 2,594.09 Mt (accounting for 22.5% of total resources) and 47 deposits covered by preliminary exploration with the resources estimated at 1,778.73 Mt (15.5%). Resources of the 178 deposits, in which exploitation was abandoned, amount to 934.87 Mt and account for 8.1% of total geological resources of the dimension and crushed stone. The economic resources amounted to 3,679.11 Mt, in 2020 increasing by 105.84 Mt (3.0%) in comparison with 2019.

In 2020, according to the data provided by concession holders of the currently exploited deposits, output of dimension and crushed stone amounted to 76.56 Mt and decreased in comparison with 2019 by 2.15 Mt (2.73%). In terms of the output volume, sedimentary rocks are most important: limestone and dolomite – account for 44.48% of total domestic output, and sandstone – accounts for 11.17% of total output. Among the igneous rocks, granite, basalt and melaphyre are being exploited in the greatest amounts – accounting for 13.50, 8.84 and 5.53% of total output, respectively. Metamorphic rocks are of minor importance when considering the output of solid rocks (total share of the domestic output of 9.16%). In comparison with 2019, output of sedimentary rocks decreased by 0.85% (0.37 Mt), whereas that of metamorphic rocks decreased by 7.09% (0.53 Mt). The output volume of igneous rocks decreased by 4.50% (1.24 Mt) and the drop pertained to almost all lithological types of these rocks (melaphyre, gabbro, basalt, porphyry and diabase). The rock mining is concentrated within the area of 2 voivodeships: Dolnośląskie, which accounts for 40.8% of domestic output of dimension and crushed stone (260 deposits and 51.8% of the domestic resources), and Świętokrzyskie with a total share of output of 34.5% (142 deposits and 21.7% of the domestic resources). Following them are: the Małopolskie voivodeship accounts for 12.0% of total output (103 deposits and 11.2% of the domestic resources), Śląskie (5.0% of domestic output), Opolskie (4.2%), Podkarpackie (2.8%) and Łódzkie (0.6%). The shares of the remaining voivodeships do not exceed 0.1%. Dimension and crushed stone can also be obtained during brown coal exploitation. In 2020, there were 1.99 kt of erratic boulders, 3.43 kt of quartzite and 769.19 kt of limestone exploited in the KWB Bełchatów SA mine (the Szczerców field).

Table 11.9.2. Resources and output of lithological types of rocks used as road and building stones [kt]

Lithological types of rocks	Resources	Output	No of deposits
TOTAL RESOURCES	**11,521,437**	**76,564**	**741** [(1)]
IGNEOUS ROCKS	4,564,096	26,391	174
Basalt	556,542	6,772	41
Diabase	20,760	107	2
Gabbro	557,353	2,128	6
Erratic boulders	1,065	–	5
Granite	1,879,131	10,337	77
Granodiorite	149,615	381	9
Melaphyre	504,230	4,236	15
Porphyry	788,222	1,508	11
Syenite	77,252	922	6
Porphyric tuff	29,925	–	2
METAMORPHIC ROCKS	1,446,927	7,010	62
Amphibolite	173,380	2,118	11
Gneiss	484,967	1,205	16
Hornfels	2,922	–	2
Cristalline schist	1,807	–	2
Marble	247,975	24	16
Dolomitic marble	214,220	635	7
Migmatite	201,398	2,451	2
Serpentinite	82,443	577	4
Greenstone	37,815	–	2
SEDIMENTARY ROCKS	5,510,414	43,162	542
Chalcedonite	37,445	50	3
Dolomite	1,254,423	15,507	53
Schist	2,014	–	1
Menillite schist	590	–	1
Marl	1,534	24	6
Opoka	1,877	–	2
Sandstone	20,785	4	11
Quartzitic sandstone	1,704,506	6,573	300
Graywacke	226,542	1,978	7
Travertine	83,666	455	5
Limestone	1,784	21	1
Dolomitic limestone	1,908,433	12,548	142
Limestone and dolomite	244,718	6,003	8
Conglomerate	22,099	–	2

[1] More than one lithological type of raw material occur in over a dozen deposits.

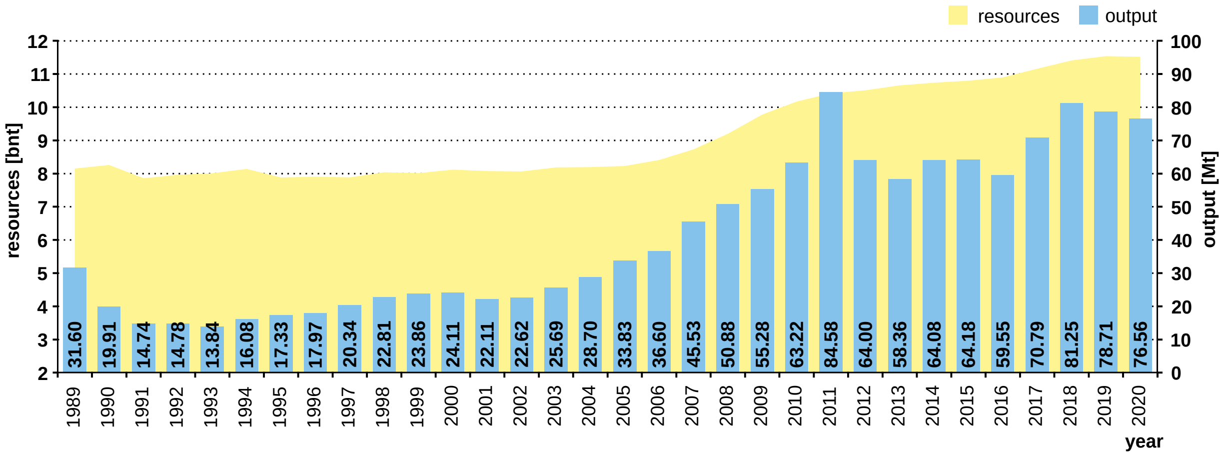


Figure 11.9.2. Dimension and crushed stone anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Table 11.9.2 shows the current state of documented resources and output volumes of individual lithological types of rocks used in road and building construction.

For the last 30 years, the resource base of dimension and crushed stone has been generally increasing despite intensive exploitation (Fig. 11.9.2). In the 1990s, resources were increasing at an average annual rate of 0.3%. The next decade brought more intensive resource growth to 2% annually, whereas the 2010–2019 period was characterized by significant fluctuations in resource volumes with an annual increase of 1.7%. In 2018, the largest amount of resources in history was recorded – amounting to 81.25 bnt.

Until 2006, the structure of available resources was quite stable: igneous rock resources were increasing by 0.4% annually on average, metamorphic rock resources, after a 16% decrease in 1995, remained steady during the following years, whereas the resources of sedimentary rocks – after significant decreases in the first half of 1990s – were increasing steadily (by about 1% annually on average). Moreover, the sedimentary rocks resources drop resulted in their total magnitude in 1995–1997 almost equal with the resources of igneous rocks. In the following years, the advantage of sedimentary rock resources over igneous rock resources began to increase. Since 2016, most significant changes have been recorded in metamorphic rock resources – after several years of stagnation, their resource volume increased by 5.5% annually – to its largest recorded amount of 5.6 bnt in 2019. A similar tendency, but less dynamic, was recorded for sedimentary rocks – their resources were increasing by an average of 2.4% annually. Regarding igneous rocks, their resources in the 2016–2020 period have been increasing by an average of 1.5% annually.

Dimension and crushed stone output was dynamically increasing from 1993 to 2011 – in 2011 when 84.58 Mt was obtained regarding the last 20-year period. The intensive supply of dimension and crushed stone, as well as of crushed aggregates, was a result of growing demand in a building sector, after the financial means of the Instrument for Structural Policies for Pre-Accesion (ISPA) tools and pre-accession European Union programs (aiming to transport infrastructure development) became available. Poland's accession to the EU in 2004 and the implementation of large financial means for sectoral programs resulted in increasing demand for crushed aggregates and building stone. In particular, the public road and railway sectors demanded adequate supply of aggregate and other stone material. An additional factor increasing the demand for stone materials was the infrastructural investments connected to the organization of the 2012 UEFA European Championship by Poland and Ukraine. Output increases were also caused by proprietary changes in a mining sector, the application of modern extractive technologies and devices, and the modernization of processing plants. Decorative qualities of stones were also a minor deciding factor on more intensive stone element usage. Output fell significantly in 2012 – by 20.6 Mt (that is by 24%) in comparison with 2011. In the 2013–2016 period, the exploitation remained between 58.36–64.18 Mt. This was accredited to lower demand from the road building and general building sectors. The next 4 years (2017–2020), brought a sharp increase in output to 70.79–81.25 Mt, followed by a declining output in the last 2 years.

An analysis of the number of deposits, resources and output shows that deposits with resources exceeding 50 Mt account for about 8% of the total number of deposits contain about 52% of total resources and account for about 53% of total domestic raw material output. Regarding quantity, in 2020, deposits with resources below 1 Mt were most common. They account for about 35% of the total number of deposits, whereas their aggregated resources and output account for less than 1% of each. Deposits with resources in the range of 1–5 Mt comprise 22% of the total number of deposits, nearly 4% of total resources and slightly above 3% of total output. A pattern can be noticed, that with increasing deposits resources, the number of deposits decreases, whereas their share in total raw material resources increases. Deposits with resources above 100 Mt account for slightly over 2% of total number of deposits, whereas their resources account for 26% of total resources and generate more than 22% of total output. Small range operations (less than 500,000 t per year) dominate the structure of mining volumes from dimension and crushed stone deposits. Large mining operations occur relatively rarely. This structure changed in subsequent years – the frequency of large-scale mining gradually increases – mining plants with an output of 1 Mt and more begin to play an important role. In terms of volume, operations of less than 10 kt annually prevail (this occurs in approximately 27% of deposits, with total extraction accounting for approximately 0.2% of global output). As the production volume increases, the number of deposits belonging to this range decreases, whereas their share in the global output increases. Deposits in the output range exceeding 1 Mt (approximately 9% of the total number of deposits exploited) account for nearly 44% of global output of dimension and crushed stone.

11.10. Dolomite

M. Tymiński

Dolomite in Poland is generally divided into 2 groups: industrial dolomite and dolomite for crushed stone production. Industrial dolomite is widely used for smelting iron and steel (as a flux), in a glass industry (so-called dolomite flours), ceramic industry, refractory industry (roast dolomite) and in the agriculture sector. The dolomite deposits which are used in a construction industry and in road construction (as building and crushed stones) are discussed separately in the Chapter 11.9.

The industrial dolomite deposits occur in southern Poland, mainly in the Śląskie voivodeship, and only 1 deposit documented in the Dolnośląskie voivodeship (Plate 6). Deposits of the best quality, matching limit criteria for smelters, occur in the Silesian-Cracow region. The deposits are of a stratified type, Devonian and Triassic in age. The second type of dolomite deposit forms lenses within metamorphic schists in the Sudety Mts. Such dolomites are used in the ceramic industry, the construction industry, and in road constructions. The best known of them is the Rędziny deposit. However, the biggest deposit of this type (Ołdrzychowice-Romanowo), located in an area of the Kłodzko Basin, is placed in the Chapter 11.9 as the raw material from the deposit is a basic component for the production of building grits.

In the latest edition of "The balance of prospective mineral resources of Poland", an assessment of prospective dolomite resources in Poland was updated (Galos, Smakowski, 2020). The main criteria adopted for establishing industrial dolomite deposits were: overburden thickness (maximum of 15 m), overburden thickness to deposit thickness ratio (maximum 0.3) and MgO content (minimum of 16%). Moreover, quality requirements for the raw material were taken into account in terms of Fe_2O_3, Al_2O_3, CaO and SiO_2 contents – it defines raw material suitability for a particular industrial application. As a result of said action, prognostic dolomite resources of were assessed to amount to 504.20 Mt, and could be found within 12 areas – 8 of them in the Dolnośląskie voivodeship, 3 in the Śląskie voivodeship and 1 in the Świętokrzyskie voivodeship.

In 2020, anticipated economic resources of dolomite amounted to 496.15 Mt, whereas anticipated economic resources of exploited deposits amounted to 202.05 Mt and accounted for 40.72% of total anticipated economic resources (Tab. 11.10.1). The resources covered by detailed exploration (categories A+B, C_1) amounted to 338.13 Mt (68.15% of total anticipated economic resources). Such explored resources within deposits being exploited accounted for 98.12% of the anticipated eco-

Table 11.10.1. Dolomite resources [Mt]

	Number of deposits	Geological resources in place			Anticipated sub-economic	Economic resources in place as a part of anticipated economic resources
		Anticipated economic				
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**11**	**496.15**	**338.13**	**158.01**	**7.08**	**125.47**
Including resources of exploited deposits						
Deposits of operating mines	4	202.05	198.26	3.79	6.53	125.47
Including resources of non-exploited deposits						
TOTAL	5	260.21	105.99	154.23	0.55	–
1. Deposits covered by detailed exploration	3	209.74	105.99	103.76	0.55	–
2. Deposits covered by preliminary exploration	2	50.47	0.00	50.47	–	–
Including abandoned deposits						
Abandoned deposits	2	33.89	33.89	–	–	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

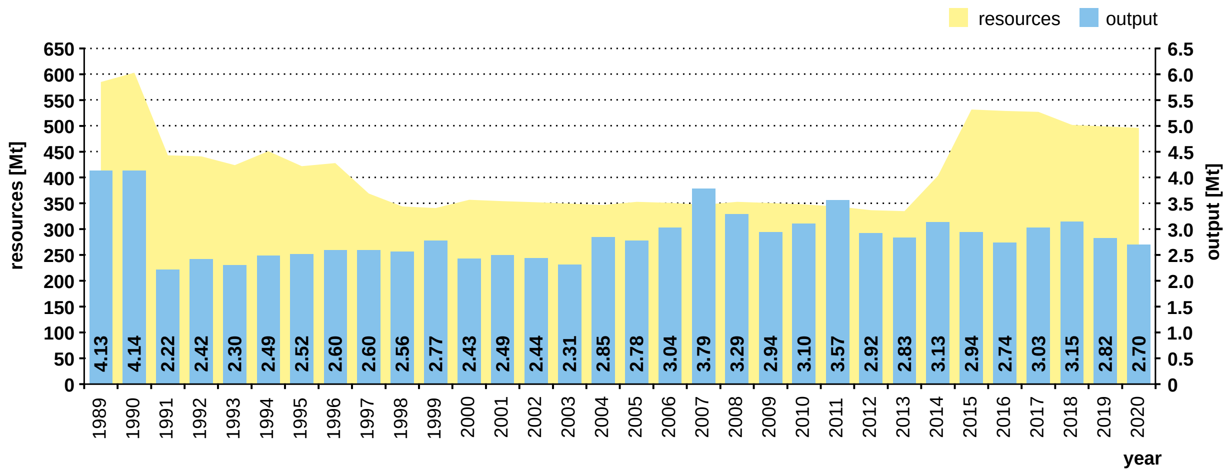


Figure 11.10.1. Dolomite anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

nomic resources (198.26 Mt). Economic resources of dolomite decreased due to exploitation and losses by 2.79 Mt (2.18%) and amounted to 125.47 Mt. These resources accounted only for 25.29% of total anticipated economic resources. The output of dolomites amounted to 2,696.93 kt in 2020 (Fig. 11.10.1).

The graph presents magnitudes of dolomite resources and output in the 1989–2020 period (Fig. 11.10.1). The resources decreased significantly in 1991 due to a new documentation approved for the Chruszczobród deposit (with smaller recalculated resources), and in 1997 due to an end of exploitation of the Bobrowniki-Blachówka and

Gródek deposits. Output fell in 1991, and after a long period of stabilization, increased in the 2004–2007 and 2010–2011 periods. The next 4 years were characterized by varying output and increasing resources. The resources growth in 2014–2015 (by 197 Mt) was due to new calculations elaborated for the Brudzowice (52.61 Mt), Rędziny (18.11 Mt), Chruszczobród (126.77 Mt) and Ząbkowice Będzińskie I (3.23 Mt) deposits. In 2014, a significant growth in exploitation was caused by the Brudzowice (by 301.8 kt) and Rędziny (38.8 kt) deposits, whereas output fell in 2015, due to the Żelatowa (93.27 kt) and Brudzowice (264.20 kt) deposits. In the 2016–2020 period, the anticipated economic resources have been systematically decreasing due to exploitation and losses and total decrease amounted to 33 Mt (6.25%). The output grew by 409 kt during 2017–2018 (from 2,738 to 3,147 kt), whereas in the last 2 years it fell by 450 kt – to 2,697 kt. The main reason was decreasing output from the Ząbkowidze Będzińskie I deposit by 595.26 kt in 2019 and by 277.45 kt in 2020. These drops were slightly compensated by an exploitation growth from the Chruszczobród 2 deposit – by 316.92 kt and 105.17 kt, respectively.

11.11. Feldspar raw materials

A. Malon

Deposits of feldspar raw materials represent natural accumulations of various kinds of feldspar and feldspar-quartzitic rocks rich in Na_2O and K_2O (concentrations of at least 6.5%) and Al_2O_3 (minimum concentration of 12%) and also with a low content of Fe_2O_3 and TiO_2 (maximum 1.5%). They are documented mainly in Lower Silesia (in the Sudety Mts. and the Fore-Sudetic region) whereas one of them is located near Cracow (Plate 6). The rocks include leucogranite occurring in the vicinities of Strzeblów (the Pagórki Wschodnie deposit) and Izery Mts. (the Kopaniec deposit), and other parts of the Lower Silesia region. Other feldspar raw materials are represented by the porphyry variety of feldspars of the Karkonosze granites from the areas of Karpniki, Maciejowa and Góra Sośnia in the Jelenia Góra Basin (Sudety Mts.), potassium trachyte from Siedlec, and Kwaczała arcose from Wygiełzowa in the Silesia-Cracow region. Prognostic resources of the feldspar raw materials are currently being assessed at 61.35 Mt, whereas prospective resources at 37.27 Mt (Sroga, Lewicka, 2020).

Feldspar is one of the major raw materials used in the ceramic industry. It is used in the form of various powders and feldspar-quartz aggregates in the manufacture of high-class porcelain and bone china, ceramic tiles, sanitary ceramics and enamel materials, and in the glass industry. Feldspars are also recovered as by-products in quarrying granite rich in potassium feldspar. In 2016, anticipated economic resources increased by 2 Mt, due to the documentation of new resources in the Stary Łom deposit, and amounted to 139.30 Mt (Fig. 11.11.1). Then, in the 2017–2020 period, the resources were systematically decreasing (by 0.22 Mt in total) due to output and losses. The Stary Łom deposit was the only deposit exploited in 2020, whereas the output of the second exploited deposit Pagórki Wschodnie was suspended. Resources of these 2 deposits represent 4% of total feldspar anticipated economic resources documented in Poland. The substantial increase of the anticipated economic resources of feldspar in the long 1989–2020 period took place in the years 2005–2008 – with the resources increasing by 50%. The 4 new deposits were recognized in this period. The economic resources of developed deposits were estimated in 2020 at 5.19 Mt (Tab. 11.11.1).

In 2020, production of feldspar raw materials amounted to 29.44 kt (only from the Stary Łom deposit). There were 2 deposits (Stary Łom and Pagórki Wschodnie) exploited in the 2016–2020 period, with the majority of the output coming from the Stary Łom deposit. This deposit has been exploited since 2011, with output amounting to 1.44 kt in 2011, then (in 2012–2017 period) the exploitation was increasing to a maximum of 89.7 kt in 2017, and then decreased to 29.44 kt in 2020. The exploitation of the Pagórki Wschodnie was stopped in 2020. Taking into account the longer period, the highest output of feldspar was recorded in the years 2003–2008. The growth of resources and high production was related to the demand from the ceramic and glass industries.

The demand for feldspar raw materials remains high in Poland. The domestic production of feldspar is used mainly for the manufacture of ceramic tiles.

Table 11.11.1. Feldspar raw materials resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**11**	**139.08**	**66.81**	**72.27**	**13.18**	**5.19**
Including resources of exploited deposits						
TOTAL	2	5.82	5.82	–	–	2.60
1. Deposits of operating mines	1	5.24	5.24	–	–	2.03
2. Deposits exploited temporarily	1	0.58	0.58	–	–	0.58
Including resources of non-exploited deposits						
TOTAL	8	122.88	53.38	69.50	13.18	–
1. Deposits covered by detailed exploration	5	61.50	53.38	8.12	–	–
2. Deposits covered by preliminary exploration	3	61.38	0.00	61.38	13.18	–
Including abandoned deposits						
Abandoned deposits	1	10.38	7.61	2.77	–	2.59

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

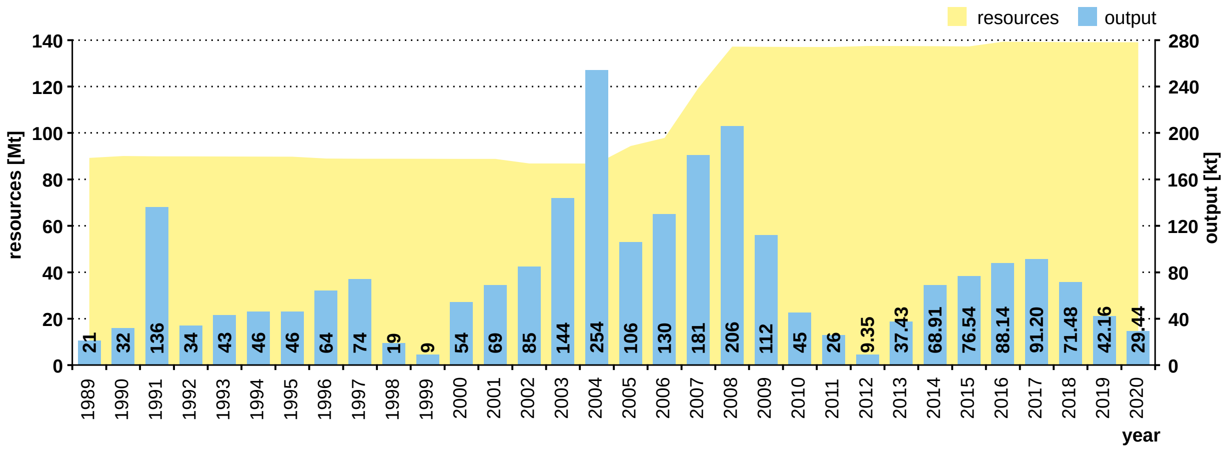


Figure 11.11.1. Feldspar anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

11.12. Filling sand

A. Malon

Filling sand is used in making hydraulically placed fill – a mixture of sand and water to fill voids created by underground mining. Deposits of the sand should be documented within the area located less than 50 km from the place where the raw material is to be used, because of the high transportation costs and the low unit price. In Poland, the filling sand deposits are situated mainly in the areas of intensive underground mining, especially those of hard coal in the USCB, copper mining in the Legnica-Głogów Copper District, and zinc and lead mining near Olkusz (Plate 8). The majority of filling sand deposits are situated around the USCB. Almost 80% of the anticipated economic resources were approved in this region.

Anticipated economic resources are relatively large taking into account decreasing demand from the coal-mining industry and totaled 2,505.88 Mm^3 (or about 4,260 Mt – as recalculated using weight-to-volume ratio 1.7 t/m^3) in 2020 (Tab. 11.12.1). The anticipated economic resources were generally decreasing in the 1989–2020 period, due to exploitation and also as a result of removing some deposits from the "The balance…", and due to the reassessment of documentation of the other deposits (Fig. 11.12.1). The resources of exploited deposits amounted to about 17% of the total anticipated economic resources. There are 4 exploited deposits and 1 temporarily exploited deposit in the USCB. The currently exploited filling sand deposits with the largest resources are: Pustynia Błędowska – blok IV (265.78 Mm^3) and Kotlarnia pole północne (77.63 Mm^3). Economic resources of the raw material amounted to 48.27 Mm^3 in 2020.

Table 11.12.1. Filling sand resources [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**31**	**2,505.88**	**1,975.05**	**530.83**	**399.55**	**48.27**
Including resources of exploited deposits						
TOTAL	6	424.02	367.02	57.00	39.42	36.74
1. Deposits of operating mines	5	360.71	303.72	57.00	–	33.92
2. Deposits exploited temporarily	1	63.30	63.30	–	39.42	2.82
Including resources of non-exploited deposits						
TOTAL	16	1,763.18	1,299.52	463.65	187.91	–
1. Deposits covered by detailed exploration	12	1,348.72	1,296.71	52.02	111.73	–
2. Deposits covered by preliminary exploration	4	414.45	2.82	411.64	76.18	–
Including abandoned deposits						
Abandoned deposits	9	318.69	308.51	10.18	172.22	11.53

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

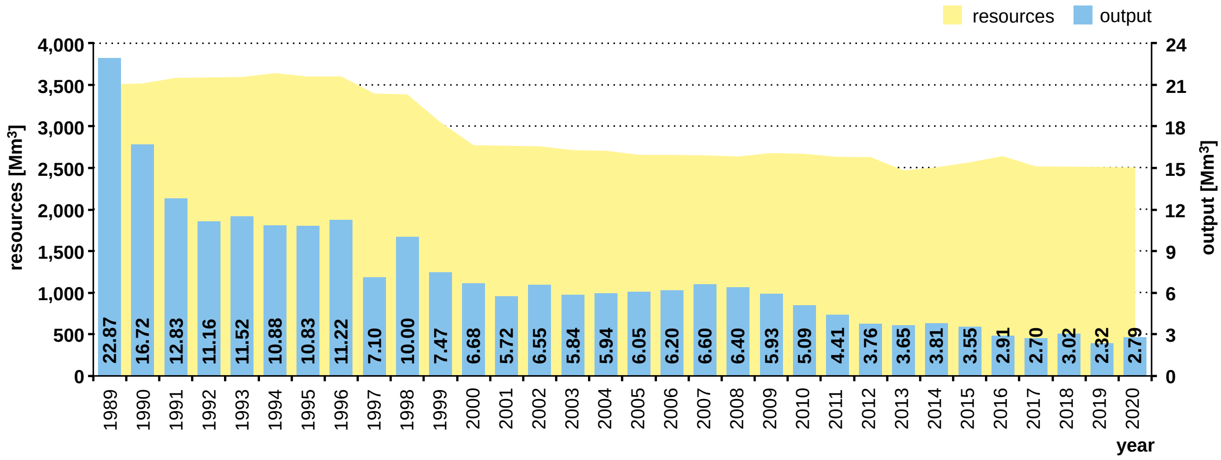


Figure 11.12.1. Filling sand anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

In the years 1989–2020 the output of filling sand have been generally decreasing due to the hard coal production decrease during this period and the fact that substitutes of ash from power plants have been mainly used in larger scale. In 2020, production of filling sand totaled 2.79 Mm³ (4.74 Mt). About 60% of output was recorded from 4 deposits in the USCB, however the deposit with the largest annual rate of exploitation (1.08 Mm³) was the Obora deposit near Lubin, in south-western Poland.

11.13. Flint

D. Brzeziński

Flint usually occurs as silica concretion of a spherical or irregular shape, clearly manifested from the ambient rocks. It occurs mostly as so-called flint banks and bars, mainly among Jurassic and Cretaceous carbonate rocks. The main component of flint concretions is chalcedony. In view of its weathering resilience, flint often occurs in secondary accumulations, as a component of loose clastic sediments. Ground flint is used in the glass and ceramic industries. It is also used in the abrasive materials industry, for the production of loose abrasives and abrasive papers. Other uses include the production of facings, millstones for rolling mills, and flint abrasives.

Table 11.13.1. Flint resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**2**	**0.03**	**0.03**	–	–	–
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	2	0.03	03	–	–	–

Striped flint is used as decorative stone to make some jewelry and stone decorations. The most famous accumulation of flint is the Krzemionki Opatowskie deposit, located near Ostrowiec Świętokrzyski, where flint has been intensively extracted as early as the Neolithic period (3,500–1,600 BC), from Upper Oxfordian limestone.

There are 2 documented deposits of flint in the Holy Cross Mts., near Kielce (the Świętokrzyskie voivodeship) – Bocheniec and Tokarnia. In Tokarnia striped flint occurs. Due to the building of the S7 expressway junction “Tokarnia”, on the section between Chęciny and Jędrzejów, a possibility of exploitation of the south-eastern part of the deposit was significantly limited. For the last 25 years flint deposits have not been exploited, and their geological resources have not changed, amounting to 27.70 kt (Tab. 11.13.1).

11.14. Foundry sand

A. Malon

Foundry sand (SiO_2 content >96%) with a low content of alkali pollutants, which is characterized by a high sintering temperature, is the basic raw material for preparing molds and core sand mass (constituting up to 90% of such a mold mass) used in metal casting. There are 2 types of foundry sand differentiated on a basis of cement and carbonate content: pure quartz sand and natural binder foundry sand. The raw material exploited from some of foundry sand deposits can also be used for other applications. Pure quartz sand is used as glass sand or sometimes as sand for the building construction and road construction industries.

Table 11.14.1. Foundry sand resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**72**	**299.63**	**148.38**	**151.25**	**5.99**	**20.26**
Including resources of exploited deposits						
TOTAL	5	47.39	47.39	–	0.39	16.56
1. Deposits of operating mines	4	46.81	46.81	–	0.25	16.17
2. Deposits exploited temporarily	1	0.58	0.58	–	0.14	0.39
Including resources of non-exploited deposits						
TOTAL	37	192.64	45.17	147.47	2.79	–
1. Deposits covered by detailed exploration	17	52.67	45.17	7.50	2.65	–
2. Deposits covered by preliminary exploration	20	139.98	0.00	139.98	0.13	–
Including abandoned deposits						
Abandoned deposits	30	59.60	55.82	3.77	2.82	3.70

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

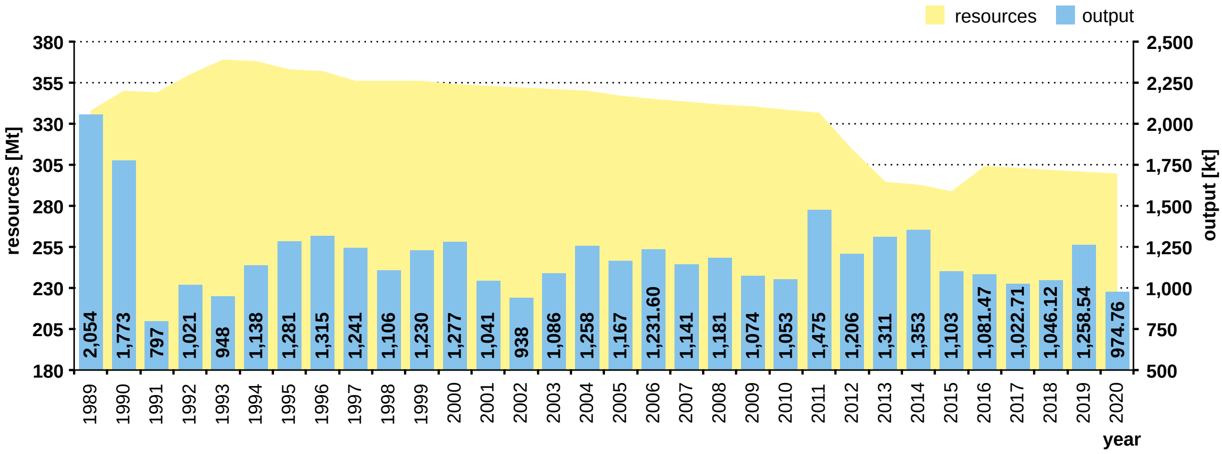


Figure 11.14.1. Foundry sand anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Deposits of foundry sand are situated mainly in the central and southern parts of Poland and usually have the form of sand sheet deposits (Plate 7). The sand deposits are Quaternary, Miocene, Cretaceous, Jurassic and Triassic in age. Considering the abundance of resources, 2 areas are most significant: the first, near Piotrków Trybunalski (Łódzkie voivodeship), and second, between Częstochowa and Zawiercie (Śląskie voivodeship). In the vicinity of Częstochowa, natural binder foundry sand occurs in infills of the karst forms that developed in the Upper Jurassic limestone, forming small natural sand deposits of variable thickness. Cretaceous foundry sand occurs mainly in the Tomaszów Basin (in the vicinity of Piotrków Trybunalski), where they are mixed with glass sand. As of end of 2018, the prognostic resources of foundry sand are assessed at 289.56 Mt, including 37.44 Mt within the Opolskie voivodeship and 252.12 Mt within the Śląskie voivodeship.

Anticipated economic resources have been decreasing over the last few years, mainly because of exploitation, and amounted to 299.63 Mt in 2020 (Tab. 11.14.1). A decreasing tendency can also be seen over a longer period (1989–2020), however resources fell only by 11% during it. Significant decreases in anticipated economic resources were recorded in 2012 and in 2013 (Fig. 11.14.1). There were 3 deposits in the Łódzkie voivodeship that were removed from "The balance…" in 2012. These deposits were re-classified as glass and foundry sand and are presented in Chapter 11.15. Also, 2 deposits (Dolnośląskie and Zachodniopomorskie voivodeships) were removed from "The balance…" in 2013, with one of them being re-classified as sand and presented in Chapter 11.26. Increases in resources were observed in: 1990, 1992, 1993 and 2016, due to approved documentation of new and existing deposits.

The anticipated economic resources of developed deposits have been decreasing in the last 4 years and amounted to 47.39 Mt in 2020.

In the 1989–2020 period, annual output of foundry sand was fluctuating near 1 Mt. In 2020 output amounted to 975 kt (Fig. 11.14.1). Almost 60% of the raw material was exploited from the Grudzeń-Las deposit near Piotrków Trybunalski, and 36% from the Szczakowa deposit, near Olkusz. Both deposits have been exploited continuously over the years: the Grudzeń-Las has been in operation since 1962, and the Szczakowa since 1973.

11.15. Glass sand and glass sandstone

A. Malon

Glass sand is a main raw material in commercial glass production. Glass sand pass through preparation and mixing in a batch, and is later transferred to a furnace for melting, to become glass. Glass sand comes from deposits of quartz sand and weakly cemented quartz sandstones rich in silica (SiO_2), and is characterized by a uniform and fine grain size, and a negligible content of coloring oxides.

In Poland, deposits of glass sand and glass sandstone occur in 10 voivodeships, with the most important deposits being: the Cretaceous sand and sandstone in the Łódzkie voivodeship – in the central Poland (east of Piotrków Trybunalski – in the Biała Góra and Unewel deposits, within the Tomaszów Basin) and the Dolnośląskie voivodeship – in south-western Poland (west of Lubin – in the vicinity of Bolesławiec) (Plate 8). Resources in the Łódzkie voivodeship contain the largest share of domestic resources (80%). In turn, the sand from the vicinity of Bolesławiec best matches raw material quality requirements for glass production. One should also note the unique white color of said sand. The Miocene and Quaternary glass sand deposits from the other voivodeships are less important in terms of their resources. This sand is suitable for production of low-quality glass only. The prognostic resources of the glass sand and glass sandstone are assessed at 210.7 Mt – within the Tomaszów Basin (Galos, 2020a).

In 2020, anticipated economic resources amounted to 660.91 Mt (Tab. 11.15.1; Fig. 11.15.1). The amount of resources has been fluctuating, but has not change significantly over the last 30 years – decreasing only by about 34 Mt, mainly due to exploitation and the approved documentation of new deposits and the already documented ones. Anticipated economic resources of currently exploited deposits amount to 176.67 Mt, accounting for 27% of total anticipated economic resources.

The glass sand production has been increasing in the last 30 years. In 2020 it amounted to 2,956.13 kt – more than three times the production achieved in 1990. Most of the output (almost 70%) came from 5 deposits located in the Łódzkie voivodeship, and about 30% came from the Osiecznica deposit located in the Dolnośląskie voivodeship.

Table 11.15.1. Glass sand and glass sandstone resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**38**	**660.91**	**415.24**	**245.67**	**129.26**	**87.28**
Including resources of exploited deposits						
Deposits of operating mines	7	176.67	174.12	2.55	28.65	61.13
Including resources of non-exploited deposits						
TOTAL	24	444.63	202.94	241.69	100.59	25.33
1. Deposits covered by detailed exploration	16	247.92	202.94	44.99	62.92	25.33
2. Deposits covered by preliminary exploration	8	196.70	0.00	196.70	37.67	–
Including abandoned deposits						
Abandoned deposits	7	39.61	38.19	1.42	0.02	0.83

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

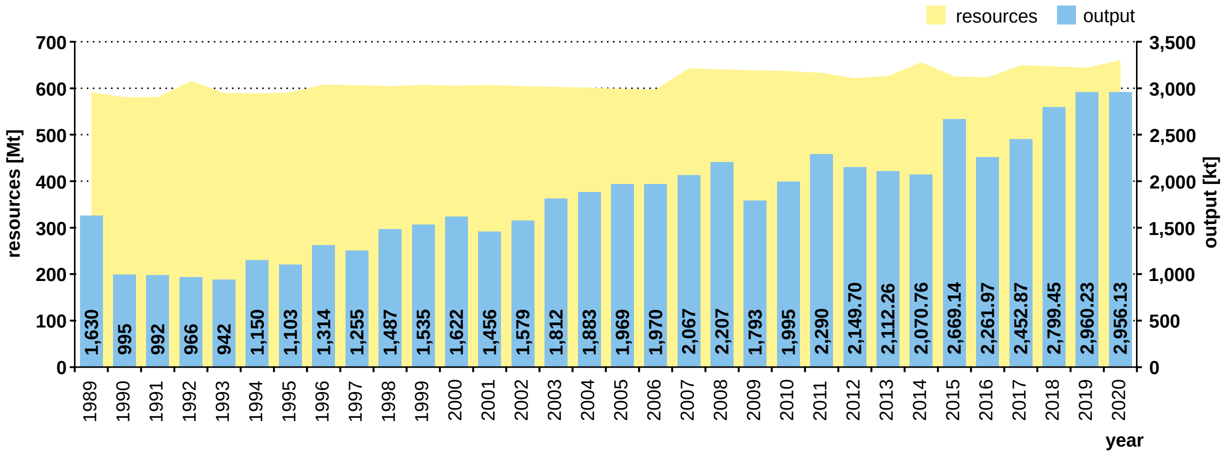


Figure 11.15.1. Glass sand and glass sandstone anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

11.16. Gypsum and anhydrite

G. Czapowski

Gypsum ($CaSO_4 \cdot 2H_2O$) is a product of seawater evaporation in a temperature lower than that necessary for precipitation of **anhydrite** ($CaSO_4$). Gypsum may also originate from the hydration of anhydrite. The fine-grained variety of gypsum is called alabaster. Finer varieties of alabaster are mainly used as ornamental and decorative stone, as well as being raw material for sculpting.

Calcined gypsum is one of the most common and ancient mortars used in building construction. At present it is widely used in the production of various building materials and prefabricates. It is also used in the production of molds for the ceramic industry. It is also added to Portland cement as a component preventing cement from flash setting. Some amounts of gypsum are used in the paint, lacquer and varnish industries, while its especially pure varieties – in surgery and dentistry. Clear colorless gypsum crystals (selenite) were used to make optical instruments. Meanwhile, anhydrite is being currently used as an additive to Portland cement, as well as being used for the production of self-leveling floors.

In Poland, deposits of calcium sulfates (gypsum and anhydrite) are associated with Miocene and Zechstein saline (halite and potassium-magnesium salts) series of evaporitic formations. In 2020, their total anticipated economic resources are located in 15 major deposits that were estimated at 252.8 Mt (a decrease by 5.84 Mt since 2015), and in the resources of 4 deposits under exploitation – at 80.9 Mt (a decrease by 45.94 Mt since 2015, caused by the closing of the Lubichów deposit; Tab. 11.16.1). The exploited deposits have the economic resources in place estimated at 62.25 Mt (a 43.97 Mt drop since 2015). Consequently the total anticipated economic resources of 4 abandoned deposits significantly increased to 43.67 Mt (from 3.57 Mt in 2015).

In 2020, the production of sulfates from the 4 operating mines amounted to over 1 Mt.

The Miocene gypsum deposits of economic importance are situated mainly along the northern margin of the Carpathian Foredeep, especially in the Nida Basin (Plate 6). In these areas, gypsum forms a thick, extensive bed, gently inclined and slightly tectonically disturbed. The gypsum bed crops out at the surface or is covered with a sedimentary blanket a few to over a dozen meters thick. The deposit series is from 3 to 46 m thick, and is characterized by a fair homogeneity of the mineral raw material, and a content of $SO_4 \cdot 2H_2O$ ranging from 85 to 95%. Deposits exploited in this region include Borków-Chwałowice and Leszcze.

Demonstrated Zechstein sulfate deposits from the Lower Silesia region (Plate 6) are characterized by significantly more complex geological conditions (strong tectonic

Table 11.16.1. Gypsum and anhydrite resources [Mt]

	Number of deposits	Geological resources in place						Economic resources in place as a part of anticipated economic resources
		Anticipated economic					Anticipated sub-economic	
		Total	A+B	C_1	C_2	D		
TOTAL RESOURCES	**15**	**252.80**	**37.37**	**148.43**	**66.99**	**–**	**20.00**	**65.25**
Including resources of exploited deposits								
Deposits of operating mines	4	80.90	5.07	56.52	19.30	–	–	65.25
Including resources of non-exploited deposits								
TOTAL	7	128.23	19.72	67.98	40.52	–	19.13	–
1. Deposits covered by detailed exploration	5	94.97	19.72	67.98	7.26	–	17.90	–
2. Deposits covered by preliminary exploration	2	33.26	–	–	33.26	–	1.23	–
Including abandoned deposits								
Abandoned deposits	4	43.67	12.58	23.93	7.16	–	0.87	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

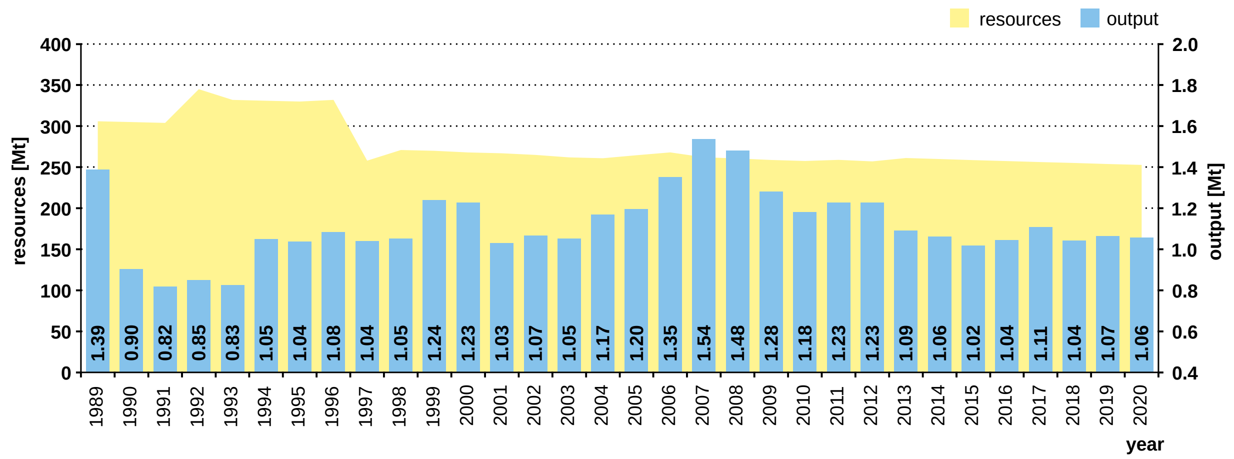


Figure 11.16.1. Gypsum and anhydrite anticipated economic resources and output in 1989–2020

According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

disturbances), and a variability in the quality of the mineral raw material. These are mainly deposits of anhydrites, with secondary gypsum formed as a result of gypsification of the anhydrite in aggressive groundwater infiltration zones. 2 deposits exist in that region: Nowy Ląd and Nowy Ląd-Pole Radłówka; an older deposit, Lubichów, was closed in 2015. The deposits occur at a depth of 0–150 m, their thickness ranges from 6.0 to 34.0 m, and $CaSO_4 \cdot 2H_2O$ content ranges from 4.1% (in anhydrite) to 92.44% (in gypsum). Moreover, the resources of shallow-seated parts of unexploited gypsum and anhydrite deposits, associated with copper ores of the Lubin-Głogów Copper District and made accessible through the mining complex of the copper mines, are estimated at 57 bnt.

In accordance with the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987), gypsum deposits are explored down to a depth of 50 m and those of anhydrite – down to 400 m. Minimum thickness accepted for gypsum deposits is 2 m, while for anhydrite it is 5 m. The accepted minimum content of usable components equals 60% for anhydrite and 80% for gypsum, and a maximum ratio of thickness of overburden to that of a deposit is 0.5 in the case of gypsum.

In the 1989–1991 period, anticipated economic resources of sulfates (gypsum and anhydrite) in 13 deposits have decreased slowly from 302 to 300 Mt due to production. This was followed by their rapid increase to almost 342 Mt in 1992, which was the result of reevaluating resources in the Lubichów deposit and establishing new resources in the cap rock of the Wapno salt diapir (Fig. 11.16.1). In 1993, a decrease to just over 328 Mt was mainly the effect of reevaluating the resources of 2 deposits (Winiary and Borków Chwałowice). This amount remained constant until 1997, when it decreased distinctly to just over 257 Mt, due to the depletion of resources of the now-abandoned Dzierżysław deposit. The next increase happened in 1998, to over 271 Mt, as theresult of reevaluating the resources of 3 deposits in the Fore-Sudetic area (Nawojów Śląski, Nowy Ląd-Pole Radłowka and Lubichów). In the 1998–2003 period, the anticipated economic resources decreased to over 262 Mt due to production. Significant growth was recorded in the years 2005–2006 (to 268 Mt), thanks to new estimations of the Leszcze and Nowy Ląd deposit resources. From then until 2015, total amount of anticipated economic resources stabilized at around 260–262 Mt and then decreased to the current amount of just over 258 Mt. All registered losses resulted mainly from production and resource reevaluation of active mines. In the last period (2016–2020) total anticipated resources of sulfates decreased from 257.53 to 252.80 Mt due to the closing of Lubichów deposit and production (Tab. 11.16.2).

Table 11.16.2. Sulfates (gypsum and anhydrite) anticipated economic resources and output in 2016–2020

Years	Anticipated economic resources [Mt]	Output [Mt]
2016	257.53	1.04
2017	256.32	1.11
2018	255.23	1.04
2019	253,89	1.06
2020	252.80	1.06
TOTAL OUTPUT (2016–2020)		**5.31**

In 2020, the predicted resources of sulfates (gypsum and anhydrite) in Poland were estimated at about 575.7 bnt, including the prognostic resources amounting to 483.98 bnt and prospective resources amounting to 91.74 bnt (Sztromwasser *et al.*, 2020).

In the years 1989–1991, there was a rapid decrease in the production of sulfates, from 1.39 to 0.82 Mt (Fig. 11.16.1), due to the economic transition taking place in during said years. Later output fluctuations: a slow increase to 1.23–1.24 Mt per year in the 1999–2000 period, followed by a decrease to 1.03–1.07 Mt in 2001–2003, and next an increase to 1.48–1.54 Mt in 2007–2008, all reflected the changing demand for housing in the same years. An observed successive decrease of annual production during the 2009–2015 period, to a steady amount of over 1 Mt, was due to the response for this continuous declining tendency in the national economy. In the 2016–2020 period, the constant annual output of active mines (1.04–1.11 Mt) was continued and total production of sulfates amounted to 5.31 Mt (Tab. 11.16.2).

In 2020, Poland exported over 199.4 kt of gypsum and anhydrite, while importing about 17.31 kt.

11.17. Kaolin

A. Malon

Kaolin, also called china clay, refers to soft clay rock, from white to yellowish in color, mainly built of kaolinite group minerals. Kaolin is created as the result of weathering or hydrothermal decomposition of igneous and metamorphic rocks, rich in feldspar. From an origin point of view, differentiation is made between residual kaolin that is derived from *in situ* decomposition of parent rocks, and sedimentary kaolin, formed as the result of being washed out from weathered parent rock, and being transported and deposited in another location.

Table 11.17.1. Kaolin resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**16**	**226.43**	**126.78**	**99.65**	**46.05**	**45.37**
Including resources of exploited deposits						
Deposits of operating mines	2	53.41	27.31	26.10	–	45.37
Including resources of non-exploited deposits						
TOTAL	11	124.31	50.76	73.55	41.67	–
1. Deposits covered by detailed exploration	6	53.07	50.76	2.31	29.67	–
2. Deposits covered by preliminary exploration	5	71.24	0.00	71.24	12.00	–
Including abandoned deposits						
Abandoned deposits	3	48.72	48.72	–	4.38	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

In Poland, kaolin also refers to the Upper Cretaceous sandstone with kaolinite cement occurring in the North Sudetic Depression.

Polish kaolin deposits formed as the result of regional kaolinization which affected acidic igneous and metamorphic rocks throughout vast areas in the Foreland of the Sudety Mts., especially the Strzegom-Sobótka and Strzelin granitoid massifs, as well as some parts of the Sowie Mts. and Izery Mts. (Plate 7). In the Tertiary, weathering processes gave rise to thick weathering covers, thereby forming kaolin deposits. There are 2 types of kaolin deposits that have been identified: deposits comprising residual material and those sedimentary in nature. In both cases the deposits appear spatially related to their parent rock and confined to areas of the above mentioned massifs of granites and metamorphic rock. Prognostic resources of kaolin raw materials are assessed at 38.44 Mt and prospective resources amount to 59.97 Mt (Lewicka, 2020).

In 2020, anticipated economic resources of kaolin increased over the last 5 years (2016–2020), due to the documentation of 2 new deposits (Dunino I and Maria III-1), and amounted to 226.43 Mt (Tab. 11.17.1). The Maria III-1 deposit was documented as a part of the Maria III deposit, where exploitation was taking place. There were 2 deposits being exploited in 2020 (Dunino and Maria III-1) and their resources amounted to 53.41 Mt (24% of anticipated economic resources). In the 2016–2020 period, the output of kaolin raw materials fluctuated around 300 kt: it increased to 300 kt in 2016, and fell in 2017 to 285 ka, and increased again in 2018–2019 to 311–317 kt, and amounted to 293 kt in 2020. In the long term (1989–2020) anticipated economic resources remained at about 200 Mt and the output fluctuated from 215 to 351 kt (Fig. 11.17.1). Currently, most of kaolin (99%) is extracted from the Maria III-1 deposit. In 2020, exploitation of this deposit gave 291 kt, while the Dunino deposit produced only 1,940 t of raw material. Kaolin is also being obtained as a by-product in exploitation of glass sand and foundry sand.

High-quality kaolin materials, that are these representing a grain size fraction below 15 μm, are used in the manufacturing of ceramics, rubber, polymers and fiberglass. In turn, coarser fractions find use in making recently fashionable ceramic wall and floor tiles of the “gres porcellanato” type, production of which requires washed kaolin with a very low content of coloring oxides such as TiO_2 and Fe_2O_3. Kaolin is also used as a raw material for the manufacture of stoneware ceramics, white cement and fireproof products.

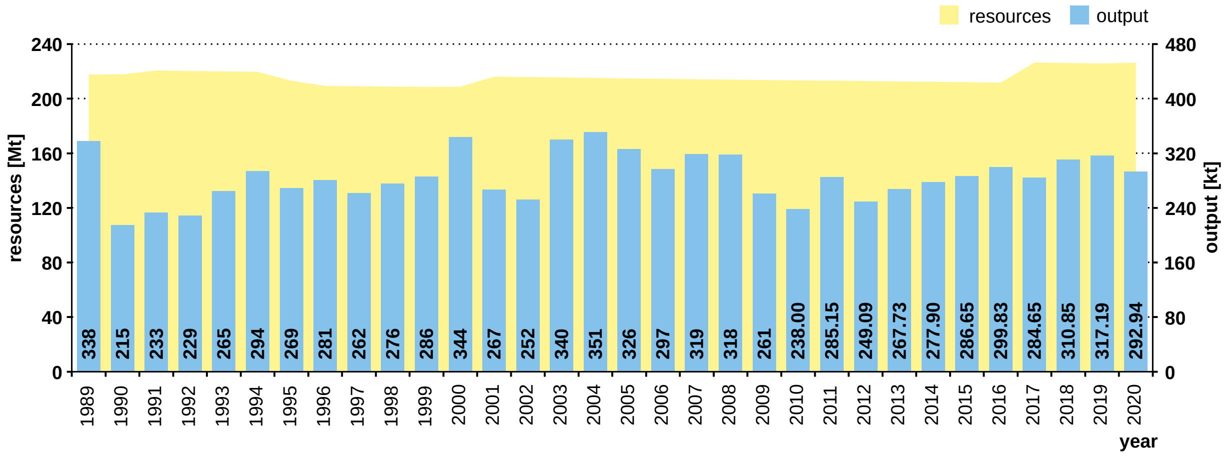


Figure 11.17.1. Kaolin anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

11.18. Limestone and marl for the cement and lime industries

D. Brzeziński

This section deals with limestone and marl deposits exploited for use in the lime or cement industries. Compact varieties of limestone used for dimension and crushed stone, and lacustrine limestone (lacustrine chalk) and proper ("writing") chalk used in industries other than cement and lime, are discussed in chapters 11.6 and 11.9. The limestone with a $CaCO_3$ content exceeding 90% is used as raw material in the lime industry. The types of limestone meeting additional (mainly chemical) criteria are used in the chemical industry, the metallurgical industry (as metallurgical flux), the sugar industry, and for production of lime powder, including sorbents for flue gas desulfurization. When used as a so-called "unfinished raw material" in a manufacture of a cement clinker, they should be supplemented with an addition of clay raw material. Some of the soft varieties of limestone and waste coming from quarries are used in agriculture for the production of powdered calcium carbonate purposed for the reduction of soil acidity. The marly limestone and marl are only useful by the cement industry. In this case, $CaCO_3$ content can be much lower (below 80%), however other chemical ingredient contents and their percentage ratios are quite important.

The cement and lime raw materials occur quite commonly in various geological formations, mainly in southern and central Poland. The majority of resources occur within 4 regions: the Świętokrzyskie, Lubelskie and Opolskie voivodeships, and the Kraków-Częstochowa-Wieluń Upland (Plate 6). Nearly 60% of documented resources are Jurassic in age. The Devonian, Triassic and Cretaceous limestones are also quite important, whereas the Precambrian, Cambrian, Carboniferous and Neogene limestones are of minor importance. From a lithological point of view, limestone and marl deposits dominate (about 41% of documented resources), followed by limestone deposits (about 38% of documented resources), and marl and chalk deposits (about 18% of documented resources). Opoka deposits are subordinate. In some of the deposits (Bratkowszczyzna, Bukowa, Gliniany-Stróża, Górażdże, Kodrąb-Dmenin, Krasocin, Stobiec, Strzelce Opolskie I and Tarnów Opolski-Wschód) both raw material types occur, that is both limestone and marl for the cement industry, and lime for the lime industry. Limestone and marl deposits are documented to a depth allowing economic and technologically possible open-pit exploitation. According to the economic criteria and parameter limits that define a deposit and its boundaries, maximum overburden thickness cannot exceed 15 m and maximum overburden thickness to deposit thickness ratio cannot exceed 0.3. Additional requirement for marly limestone and marl deposits are put forth by the lime industry is a weighted minimum average of $CaCO_3$ that should be above 90% in the entire deposit profile.

Table 11.18.1. Limestone and marl for the cement industry resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**70**	**12,688.55**	**7,106.31**	**5,582.24**	**1,024.49**	**1,927.47**
Including resources of exploited deposits						
TOTAL	20	4,331.06	3,434.54	896.52	144.78	1,882.28
1. Deposits of operating mines	18	4,000.65	3,115.99	884.67	144.78	1,804.03
2. Deposits exploited temporarily	2	330.41	318.55	11.86	–	78.26
Including resources of non-exploited deposits						
TOTAL	48	8,350.49	3,666.38	4,684.12	877.88	45.19
1. Deposits covered by detailed exploration	33	4,392.90	3,666.38	726.53	105.21	45.19
2. Deposits covered by preliminary exploration	15	3,957.59	0.00	3,957.59	772.66	–
Including abandoned deposits						
Abandoned deposits	2	7.00	5.39	1.60	1.84	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

Prospective and prognostic resources of the raw materials for cement and lime industries (limestone and marl) concentrate mainly within 5 deposit regions: opolski, śląski, krakowsko-częstochowski, tomaszowski and świętokrzyski – these regions fit in with current centers of the cement and lime production and the production of industry limy stone. The perspective resources of raw materials for the cement and lime industries (limestones and marls) amount to about 120,381.03 Mt, whereas the majority of resources is located in the Opolskie voivodeship (about 49.8% of the resources – the Triassic and the Cretaceous limestones and marls) and the Małopolskie voivodeship (about 29.9% of the resources – the Triassic, Jurassic and Cretaceous limestones and marls). Estimated prognostic resources of industry limestones and marls amount to about 6,429.22 Mt and their distribution is concentrated in the Lubelskie voivodeship (about 68.3% of the resources – the Jurassic and the Cretaceous opokas, limestones and marls) and the Opolskie voivodeship (about 19.3% of the resources – the Jurassic and the Cretaceous limestones and "writing" chalk) (Brzeziński, 2020).

Documented anticipated economic resources of the discussed raw material group amounted as of the end of 2020 to 18,220.84 Mt including 12,688.55 Mt (69.6% of total anticipated economic resources) within 70 deposits documented for the cement industry and 5,532.29 Mt (30.4% of resources) within 124 deposits for the lime industry (Table 11.18.1; 11.18.2). In comparison with 2019, in 2020 the anticipated economic resources of limestone and marl documented for the cement industry decreased by 6.23 Mt, whereas the resources of lime documented for the lime industry increased by 96.87 Mt. Geological resources of exploited deposits (of operating mines and those exploited temporarily) account for 34.1% of resources documented for the cement industry and for 38.3% of resources documented for the lime industry. In 2020, economic resources of limestone and marl for the cement industry dropped by 93.12 Mt (4.6%) comparing with 2019 and amounted to 1,927.47 Mt. The same resources of limestone for the lime industry decreased by 11.20 Mt (0.9%) in comparison with 2019 and were equal 1,188.69 Mt. Economic resources established for exploited deposits of the raw material for

Table 11.18.2. Limestone for the lime industry resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**124**	**5,532.29**	**3,208.36**	**2,323.93**	**1,137.37**	**1,188.69**
Including resources of exploited deposits						
TOTAL	30	2,116.52	1,988.08	128.44	26.08	1,184.16
1. Deposits of operating mines	26	2,013.83	1,885.40	128.44	25.97	1,151.47
2. Deposits exploited temporarily	4	102.68	102.68	–	0.11	32.70
Including resources of non-exploited deposits						
TOTAL	60	3,140.93	957.83	2,183.10	1,079.56	4.53
1. Deposits covered by detailed exploration	42	1,226.70	895.04	331.66	629.97	4.53
2. Deposits covered by preliminary exploration	18	1,914.23	62.79	1,851.44	449.59	–
Including abandoned deposits						
Abandoned deposits	34	274.85	262.45	12.39	31.73	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

the cement industry amount to 4,331.06 Mt and account for 43.5% of their documented geological resources, whereas for the raw material for the lime industry – 2,116.52 Mt and 55.9%, respectively.

In 2020, output of the raw material for the cement industry amounted to 28.32 Mt and increased by 0.13 Mt (0.5%) in comparison with the previous year. Output of the raw material for the lime industry dropped by 0.10 Mt (0.5%) and amounted to 19.17 Mt. Rock mining of discussed raw materials has been for years concentrated in the area of 3 voivodeships: Świętokrzyskie which accounts for 46.6% (21.19 Mt) of domestic output of limestones and marls for the cement and lime industries, Opolskie with the share of 20.4% (9.70 Mt) and Kujawsko-Pomorskie – 15.5% (7.34 Mt). The most significant growth of mining activity was recorded in the area of the Łódzkie voivodeship – it accounted for almost 9% of domestic output (4.08 Mt).

Anticipated economic resources have not been changing significantly for the last 30 years (Fig. 11.18.1) – oscillating within a range of 16.67–18.44 bnt. Nevertheless, since 2004, there has been a growing tendency occurring. The growth – in spite of intensive exploitation – was mainly a result of an updating and widening of the already documented deposits resources base or a change of a raw material intended use, with new deposits documentations as a minor factor.

Output of the raw material has been characterized by cyclical fluctuations tied to an economic situation in a building sector. The highest output volumes were recorded in 1989 and 2011 – 49.85 and 49.01 Mt, respectively. In 2001–2005, output remained at a level below 30 Mt as a result of modernization of the cement industry sector. Since 2006, the production has been systematically growing – started from 34.10 Mt, through the highest level of 49.00 Mt in 2011 (numerous infrastructural investments connected with the EURO 2012 championships organized in Poland), to 47.48 Mt in 2020. The average output growth was equal about 4% annually, interrupted only in 2008 and 2009 due to the worldwide financial crisis. Such growth resulted from a growing demand for cement used

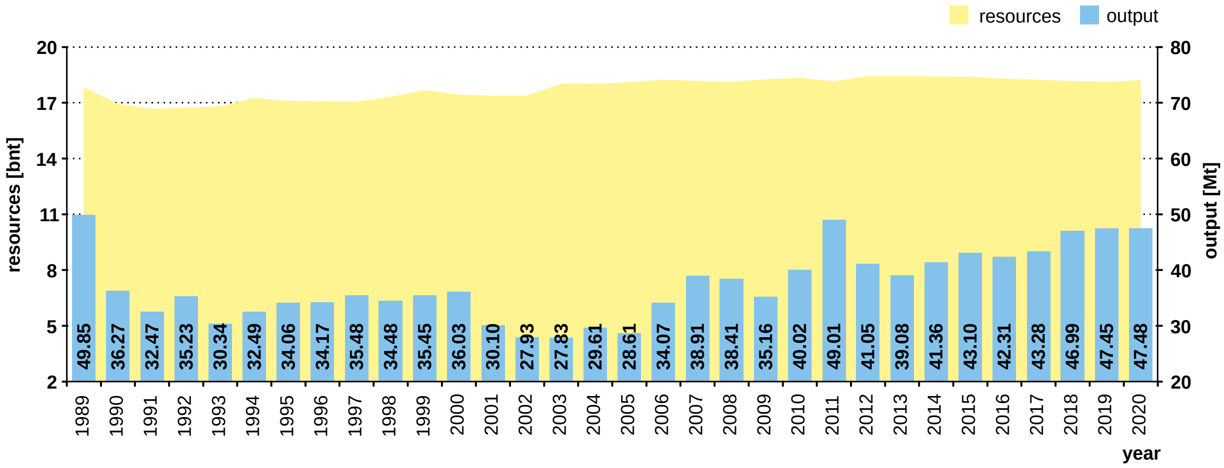


Figure 11.18.1. Limestone and marl for the cement and lime industries anticipated economic resources and output in 1989–2020

According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

in housing road construction – concrete became the most universal and economic building material and a technology of road pavements building made of cement concrete became the most popular in Poland, especially on superhighways and expressways. Quite important factor is also a regularly growing importance of a cement-lime sector in circular economy (advanced technologies of cement and concrete production allow to replaced fossil fuels with secondary raw materials and fuels coming from wastes on various production phases).

An analysis of deposit number structure, the resources and output volume shows as follows: in 2020 the most numerous – in a magnitude aspect – were deposits with resources below 100 Mt (above 72% of total deposit number), whereas their resources account for only 16.5% of total documented resources and their share in total output volume were equal only 10.4%; deposits with resources in the range from 100 to 500 Mt accounted for slightly above 25% of total deposit number and contained almost 60% of total resources volume, they also gave more than 56% of total output; the least numerous were deposits with resources exceeding 500 Mt – they accounted for only 2.6% of total deposit number, nevertheless they contained 23.7% of total resources volume and accounted for 33% of total output magnitude. In structure of an yearly output from deposits of limestones and marls for cement and lime industry, small deposits – below 1 Mt of exploitation (68.2% of exploited deposits number, with the share in total output at the level of 14%) – dominate. Deposits with the output range 1–5 Mt account for 27.3% of total exploited deposit number (accounting for 58.3% of total domestic output). Deposits with the large output volume occur seldom – only 4.5% of the exploited deposits exceed 5 Mt per year. However, their share in total output is significant and accounts for 27.7%.

11.19. Magnesite

A. Malon

Magnesite (magnesium carbonate – $MgCO_3$) is created by the erosion of magnesium-rich igneous rocks under hydrothermal conditions and forms white accumulations.

Polish magnesite deposits are located within the Precambrian Sobótka, Szklary, Grochowa-Braszowice serpentinite massifs and the Gogołów-Jordanów ultramafic massif in the Lower Silesia region (Plate 7). Up to the present, 6 magnesite deposits have been documented in this region. These are vein-type deposits, with individual veins reaching up to 3 m in thickness and being characterized by complex geological structure and high variability of raw material quality. Magnesite is currently exploited only from the strip mine at Braszowice. Prospective resources, within the 3 serpentine massifs: Gogołów-Jordanów, Szklary and Groszowa-Braszowice, are assessed at 3.25 Mt (Sroga, 2020b).

Table 11.19.1. Magnesite resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**6**	**13.50**	**3.75**	**9.75**	**2.18**	**3.47**
Including resources of exploited deposits						
Deposits of operating mines	1	3.47	3.47	–	–	3.47
Including resources of non-exploited deposits						
Deposits covered by preliminary exploration	4	5.92	0.00	5.92	2.18	–
Including abandoned deposits						
Abandoned deposits	1	4.11	0.28	3.83	–	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

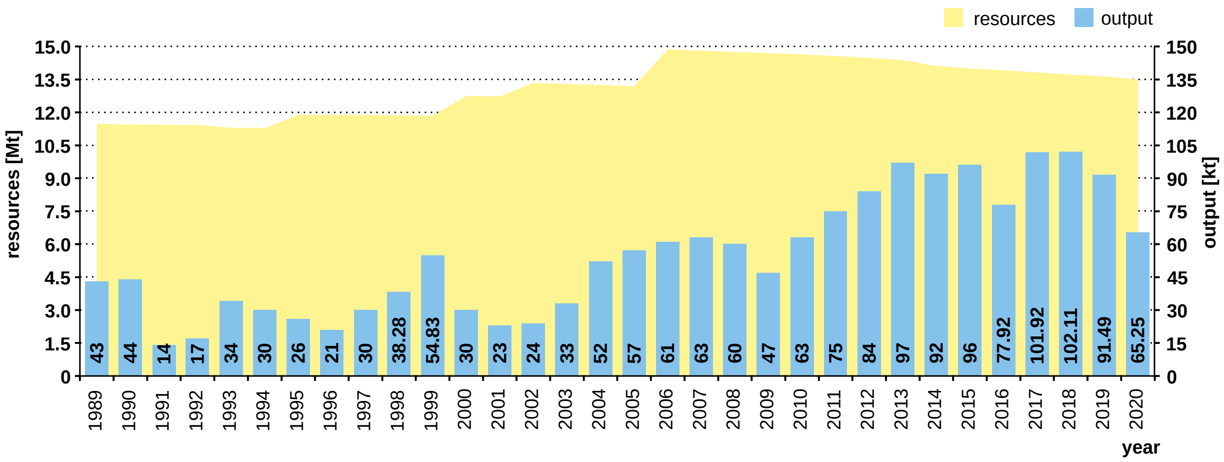


Figure 11.19.1. Magnesite anticipated economic resources and output in 1989–2020

Varied data accuracy results from source data. According to: “The balance of mineral resources deposits and groundwater resources in Poland” (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), “The balance of mineral resources deposits in Poland” (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Magnesite is used mainly as a semi-manufactured material for the production of multi-component artificial fertilizers, for purification of potable water and sewage treatment, and as a mineral additive to animal feed.

As of the end of 2020, anticipated economic resources were estimated at 13.50 Mt (Tab. 11.19.1). The resources increased due to the documentation of 2 larger raw material deposits (mainly in the Braszowice deposit) in the following years: 1995, 2000, 2002 and 2006 (Fig. 11.19.1). The decrease in resources in the years 1989–2020 was mainly due to production.

In 2020, domestic production of magnesite – from the only Polish deposit being exploited – amounted to 65 kt, decreasing significantly in comparison with the previous year. The exploitation fluctuated, but generally increased in the 1989–2020 period.

11.20. Mineral raw materials for civil engineering – earthworks

W. Szczygielski

This group of raw material deposits is documented for purposes of the earthworks sector – building of engineering objects using unfired and untreated raw earth for e.g.: road and rail infrastructure construction, embankment construction, dam, canal and levee construction, waste disposals and their insulation, and mass haul of earth mass. Data does not contain other sources of material for earthworks.

In the earthworks sector, natural and anthropogenic raw materials are used. Based on their origin, the following raw materials can be distinguished:

- local raw materials; native and anthropogenic soil, earth and rock from a construction site, collected during previous work – they are used first (especially when using cut and fill techniques).
- raw materials from external source (in the case of deficit of local raw material);
  - earth mass provided from beyond the construction site e.g. raw materials exploited from deposits such as: sand and gravel, dimension and crushed stone, or raw materials for civil engineering;
  - anthropogenic soil, earth, and rock: artificial aggregate, mining waste, industrial waste.

A long list of natural raw materials (soil, earth, and rocks) characterized by features allowing them to be used directly or after treatment for earthworks construction. It covers e.g.: crushed hard rocky soil and stony, degraded earth, rubble and pebbles, sand, gravel – including loamy and silty varieties: loamy sand with a gravelly-stone admixture (morainal); sandy silt and silt; crushed soft rocky soil; mantle rock and loamy rubbles, etc.

The GML does not specify parameter limits that define a deposit of the given raw material – it is not listed in the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987). An assessment of raw material utility and deposit boundaries is based on regulations in the construction and earthworks sectors, in terms of the rocky material quality and technical parameters of ob-

Table 11.20.1. Mineral raw materials for earthworks resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**52**	**17.26**	**16.92**	**0.34**	**0.50**	**6.36**
Including resources of exploited deposits						
TOTAL	22	11.15	10.85	0.30	0.44	5.51
1. Deposits of operating mines	13	5.31	5.01	0.30	–	3.96
2. Deposits exploited temporarily	9	5.85	5.85	–	0.44	1.55
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	22	5.68	5.68	–	–	0.85
Including abandoned deposits						
Abandoned deposits	8	0.42	0.39	0.04	0.06	–

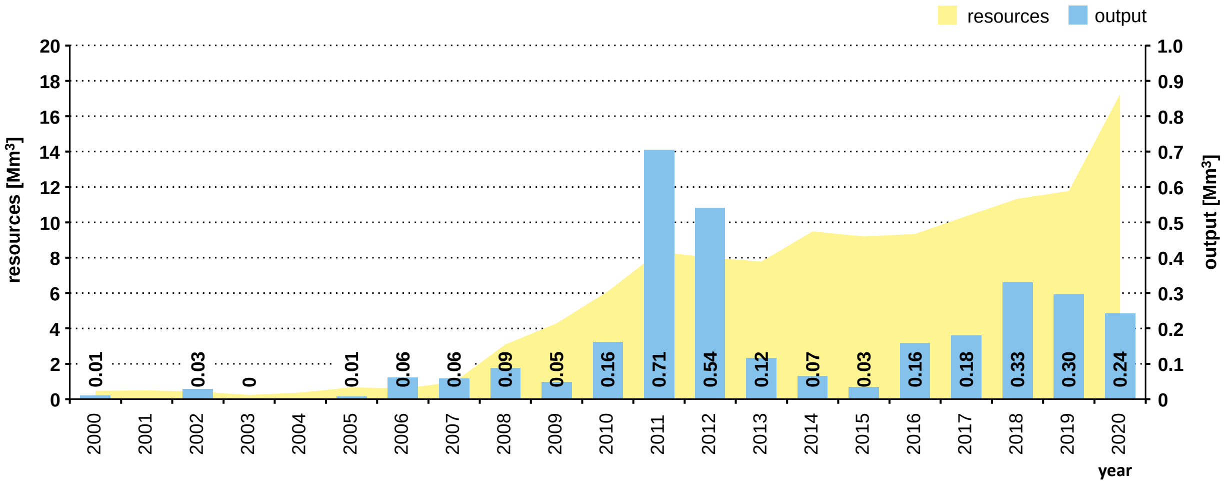


Figure 11.20.1. Mineral raw materials for earthworks anticipated economic resources and output in 2000–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

jects. Range of studies depends on a given raw material and its projected usage.

Data presented in this chapter, covering resources and output, refers only to deposits classified as deposits of raw materials for earthworks, documented and exploited according to the GML. They do not cover raw materials for the mass haul of materials obtained from other sources.

The resources usually include clastic rocks with clayey-sandy characteristics, e.g.: silty sand that does not meet the criteria established for sand and gravel deposits, loamy-clayey sediments, and solid rock: sandstone, limestone, conglomerate, allocated from dimension and building stone deposits that do not meet criteria established for crushed aggregate production. Only in about 30% of cases raw materials for earthworks are documented as a main raw material, usually they are documented as an accompanying raw material in sand and gravel deposits or dimension and crushed stone deposits.

As of the end of 2020, anticipated economic resources amounted to 17.256 Mm³ (Tab. 11.20.1) and have doubled in the last 5 years (Fig. 11.20.1).

During the 2016–2020 period, the average annual output amounted to 0.242 Mm³ (0.159–0.330 Mm³). Probably, majority of the obtained raw materials was used in communication construction sector.

The given raw material commonly occurs in Poland. The resources base and demand depend on investing plans and progresses of construction. Often, a deposit is documented for the needs of a particular investment, and after earthworks, raw material resources can be removed from "The balance…" at the request of an investor – asuseless for other purposes.

11.21. Peat

W. Szczygielski

Peat is organic sediment originating from a humid environment, and is the result of accumulation and peat-formation of organic matter (mainly of plant origin). The peat-formation process is generally based on partial organic matter decomposition in an environment with limited oxygen access. Physical, chemical and microbiological transformations occur during this process. Depending on the environmental conditions and a type of turfogenic vegetation, as well as on accumulation conditions and changes of these factors, various types of peat are formed. They differ in their appearance, composition and properties.

According to genetic features, peat is distinguished as low, high and transition. Low peat originates in fen peatlands occurring in swampy river valleys, in landscape depressions and above lake edges. This type of peat is rich in nutrients supplied by surface and deep-seated water. High peat originates in raised peatlands (or ombrotrophic peatlands) located within the zones above low peatlands, which are supplied by rainwater only. They are characterized by a low nutrient content and a higher acidity than the low peat. Transition peat combines the features of both peat types mentioned above, occurring mainly in transition zones between high and low peatlands. Most of peat originated in the late-Quaternary, mainly in the Holocene.

The distribution of peatlands and peat deposits in Poland is uneven. They commonly occur in northern and north-western Poland and in the area of Lublin. Their number, thickness and dispersion decrease in other regions. More than 50% of the peatlands are located in the northern part of Poland. They cover an area of about 1.2 Mha containing more than 17 bnm^3 of peat. At present, about 50,000 peatlands have been catalogued by the Institute of Technology and Life Sciences Institute for Land Reclamation and Grassland Farming in Falenty (previously: the Institute of Technology and Life Sciences). Of those, about 36% form a potential resource base for the exploitation of peat. Only a minor part of these areas, presented in a further part of this chapter, has been explored and can be treated as deposits within the meaning of the GML.

According to the “Regulation by the Minister of the Environment dated the 1st of July, 2015, regarding geological documentation of a mineral raw material deposit, excluding hydrocarbon fields” (Journal of Laws, 2015, Item 987) parameter limits that define a raw material deposit and its boundaries are listed in Appendix 8:

- peat deposits (table 5): minimum deposit thickness of 1 m; maximum ratio of overburden thickness to mineral deposit thickness 0.5; maximum ash content in dry peat – 30%;

Table 11.21.1. Peat resources [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**299 (2)**	**91.57**	**83.38**	**8.19**	**6.11**	**34.72**
Including resources of exploited deposits						
TOTAL	79 (1)	43.86	43.83	0.03	3.66	32.26
1. Deposits of operating mines	55	41.13	41.10	0.03	3.64	31.13
2. Deposits exploited temporarily	24	2.74	2.74	–	0.02	1.13
Including resources of non-exploited deposits						
TOTAL	137 (1)	39.12	31.19	7.93	0.97	1.10
1. Deposits covered by detailed exploration	119	31.19	31.19	–	0.80	1.10
2. Deposits covered by preliminary exploration	18	7.93	0.00	7.93	0.17	–
Including abandoned deposits						
Abandoned deposits	83	8.58	8.35	0.23	1.48	1.35

[1] In 1 deposit agricultural peat and muds are presented together.
[2] In 2 deposits (Puścizna Wielka, Bronów A) agricultural peat occurs together with muds.
The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

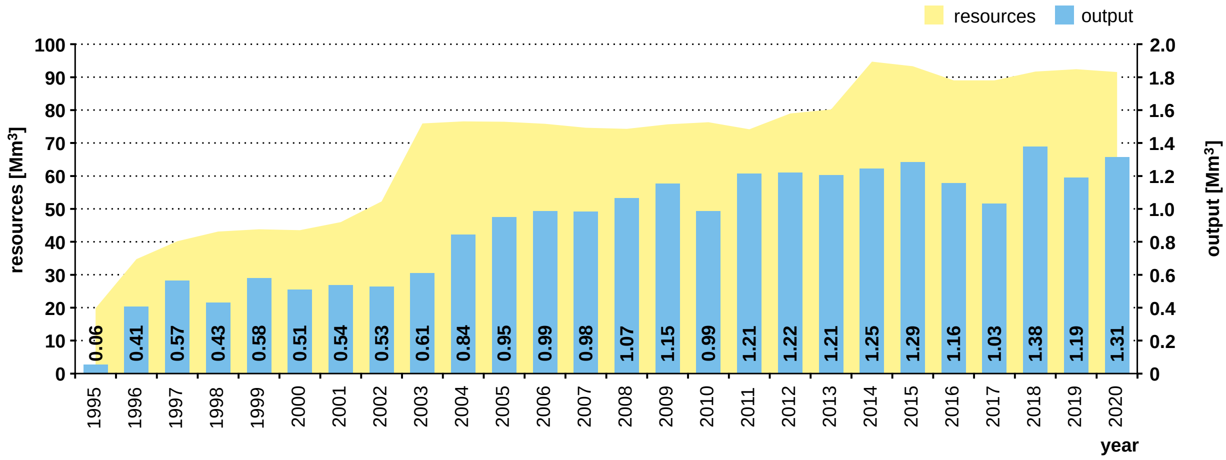


Figure 11.21.1. Peat anticipated economic resources and output in 1995–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

- therapeutical peat deposits – muds (table 6): minimum deposit thickness of 1 m; maximum ratio of overburden thickness to mineral deposit thickness 0.5; maximum non-organic matter content in dry mass 25%; minimum grade of decomposition 30% (H3); bacteriological valuation (*E. coli* titer) ≥1.0; *E. coli* perfringens titer ≥0.1;
- mud silt deposits (table 7): minimum deposit thickness of 1 m; maximum ratio of overburden thickness to mineral deposit thickness 0.5; maximum non-organic matter content in dry mass 80%; minimum grade of decomposition 30% (H3); bacteriological valuation (*E. coli* titer) ≥1.0; *E. coli* perfringens titer ≥0.1.

According to "The balance..." anticipated economic resources of peat amounted to 91.566 Mm³ within 299 deposits (Tab. 11.21.1). Total volume contained: 81.420 Mm³ of agricultural peat (88.9%) within 262 deposits, whereas resources of agriculture peat (muds) amounted to 10.146 Mm³ (11.1%) within 39 deposits (in 2 deposits there are both agriculture peat and therapeutical peat occur). The deposits cover the area of about 4.5 kha.

The average yearly peat output in Poland in the 2016–2020 period amounted to 1.21 Mm³ (1.03–1.38 Mm³) (Fig. 11.21.1), of which the output of therapeutical peat (muds) accounted for below 1%. The share of exploitation over the last 5 years of individual voivodeships were as follows: Zachodniopomorskie 24.3% (20.8–26.5%), Lubelskie 14.8% (11.4–20.1%), Mazowieckie 14.7% (13.2–16.3%), Warmińsko-Mazurskie 14.3% (10.9–18.3%), Podlaskie 9.5% (8.5–11.5%), Lubuskie 7.6% (6.8–8.5%), Pomorskie 6.8% (4.6–9.2%), Wielkopolskie 6.1% (3.2–7.2%). In subsequent 6 voivodeships, the share in total output amounted to 1.8%, whereas in the Dolnośląskie and Opolskie voivodeships it amounted to 0%.

Currently, so-called "agricultural peat" is used mainly in agriculture, gardening, fruit-farming, forestry, and in the reclamation processes. Such peat is characterized by properties improving the soil structure and air-water conditions. Peat is also a base for production of garden peat, peat bases, mineral peat mixtures, and agricultural peat.

Therapeutical peat – muds – is used in balneology for peat baths, poultices and for medical products. Peloid use in therapy is regulated by the "Act of 28th of July, 2005 on health resort treatment, health resort protection areas and health communities" (Journal of Laws of 2005, Item 1399) along with implementing acts. Such peloid has to be obtained from non-dehydrated peat deposit with documented resources and with a degree of organic matter decay above 30%, fulfilling the physical-chemical and microbiological requirements defined in the "Regulation by the Minister of Health on the scope of studies necessary to establish therapeutical features of natural therapeutical raw materials and the therapeutical feature of climate, criteria for their assessment and the certificate template confirming such features" (dated the 13th of April, 2006 – Journal of Laws of 2006, Item 565; Appendix 2: Scope of studies necessary to establish therapeutical features of peloids, Appendix 4: Criteria of assessment therapeutical features of water and gases, peloids and climate together with their usefulness for therapeutical purposes. II. Criteria for assessment therapeutical features of peloids). A list of certifiers licensed to conduct studies and to issue certificates confirming therapeutical features, can be found on the website of the Minister of Health (https://www.gov.pl/web/zdrowie).

11.22. Phyllite, quartzitic and micaceous schist

M. Tymiński

Metamorphic schist (phyllite, quartzitic and micaceous) is used in construction building, as a major component of a fine gravel coating for tar paper (phyllite and micaceous schists), in agriculture, as an inert dust pesticide carrier (phyllite and micaceous schists), and in the manufacturing of fireproof building materials, as one of the major components of fireproof cement (quartzitic schist).

Phyllite schist is documented in 3 deposits in the Opolskie voivodeship (Plate 7): Chomiąża, Dewon-Pokrzywna and Dewon-Pokrzywna 2. Total anticipated economic resources of phyllite schists amounted to 15.90 Mt as of the end of 2020 (Tab. 11.22.1). Similar to previous years, exploitation was carried out only from the Dewon-Pokrzywna deposit and amounted to 170.02 kt. The anticipated economic resources of this deposit decreased – due to exploitation, losses and better deposit exploration – by 0.29 Mt (–2.10%) and amounted to 13.33 Mt. 2 other deposits of phyllite schist are not being exploited – Dewon-Pokrzywna 2 is only covered by preliminary exploration, whereas the Chomiąża deposit has been abandoned since 1989 and the remaining resources are estimated at 0.31 Mt.

Quartzitic schist occurs within the Strzelin granite massif in the Dolnośląskie voivodeship (Lower Silesia region). The only documented and exploited deposit of that raw material in Poland is Jegłowa, and therefore, it should be particularly protected. In 2020, its anticipated resources (beyond protective pillars) amounted to 8.67 Mt and economic resources amounted to 2.74 Mt. The Jegłowa deposit is widely known for occurrences of beautiful quartz crystals, especially those clear and colorless.

Micaceous schist has been documented within 2 deposits located in the Dolnośląskie voivodeship: the Jawornica deposit in Kłodzko County, and the Orłowice deposit in Lubań and Lwówek Śląski Counties. Total anticipated economic resources of the raw material, as of the end of 2020, were estimated at 6.64 Mt and economic resources at 3.03 Mt. The resources of the Orłowice deposit account for 85.61% of anticipated economic resources and 82.95% of economic resources.

Anticipated economic resources of phyllite schist decreased over the 2016–2020 period from 16.75 Mt to 15.90 Mt – by 0.85 Mt (–5.07%) due to exploitation and losses from the Dewon-Pokrzywna deposit. In 2020 – in comparison with 2019 – the anticipated economic resources of this deposit decreased by 0.29 Mt (–2.10%). During the analyzed period, output dropped from 184.09 to 170.02 kt – by 14.07 kt (–7.64%). The biggest output decrease was recorded in 2017 (by 22.08 kt), whereas in 2020 exploitation increased by 20.51 kt in comparison with 2019 (by 13.72%). In the 2016–2020 period, quartzitic schist resources decreased only by 0.03 Mt and with said decreases being recorded only in 2019 and 2020, due to the exploitation of the Jegłowa deposit. In the 2016–2018 period, the raw material was not the subject of exploitation, whereas in 2020 output was more than twice larger than in 2019 and amounted to 14.18 kt. The resources of micaceous schist have slightly decreased since 2016 – from 6.66 to 6.64 Mt in 2020, due to the exploitation and losses from the Jawornica and/or Orłowice deposits. In 2020, after several years of continuous exploitation, the output from the Jawornica deposit was halted and only the Orłowice deposit was exploited. The size of raw material output decreased in the 2016–2019 period by 5.16 kt, whereas in 2020 there was a significant increase recorded – exploitation from the Orłowice deposit amounted to 9.20 kt.

In the latest edition of "The balance of prospective mineral resources of Poland", the assessment of resources prospective for quartzite and quartzitic schist in Poland was updated (Brzeziński, Galos, 2020). The main criteria adopted for establishing the quartzite and quartzitic schist deposits were:

- deposit thickness – minimum of 5 m,

Table 11.22.1. Schist resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
PHYLLITE SCHISTS						
TOTAL RESOURCES	**3**	**15.90**	**13.64**	**2.26**	**–**	**3.72**
Including resources of exploited deposits						
Deposits of operating mines	1	13.33	13.33	–	–	3.72
Including resources of non-exploited deposits						
Deposits covered by preliminary exploration	1	2.26	0.00	2.26	–	–
Including abandoned deposits						
Abandoned deposits	1	0.31	0.31	–	–	–
QUARTZITIC SCHISTS						
TOTAL RESOURCES	**1**	**8.67**	**5.43**	**3.24**	**–**	**2.74**
Including resources of exploited deposits						
Deposits of operating mines	1	8.67	5.43	3.24	–	2.74
MICACEOUS SCHISTS						
TOTAL RESOURCES	**2**	**6.64**	**6.64**	**–**	**–**	**3.03**
Including resources of exploited deposits						
TOTAL	2	6.64	6.64	–	–	3.03
1. Deposits of operating mines	1	5.68	5.68	–	–	2.51
2. Deposits exploited temporarily	1	0.96	0.96	–	–	0.52

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

- overburden thickness to deposit thickness ratio – maximum 0.5,
- SiO_2 content – minimum of 95%,
- Fe_2O_3+TiO_2+alkali content – maximum of 1%.

As the result of such criteria, the prospective resources of quartzitic schist were assessed to amount to 8.49 Mt within 1 area, which is strictly connected with the already documented Jegłowa deposit (the so-called layers from Jegłowa). Prospective resources were also present in the deeper parts of the Jegłowa deposit, together with the minor area of the schist outcrop west of Jegłowa deposit.

11.23. Quartz sand for production of cellular concrete and sand-lime brick

A. Malon

Sand is widely used in the production of cellular concrete and bricks and sand-lime brick in the whole of Poland. The raw material suitable for such production has to be sufficiently pure, fine-grained and well-sorted. These requirements are met by the Quaternary glacial, fluvioglacial, river and eolian sand. Sand most suitable for the above-mentioned purposes include mainly fluvioglacial and eolian sand characterized by: a high-silica content, good grain segregation (content of 0.05–0.5 mm grains should exceed 65%), high degree of grain roundness, and low content of extraneous matter. Prognostic resources of quartz sand for the production of cellular concrete and sand-lime products are assessed to amount to 82.64 Mm^3 (Galos, Miśkiewicz, 2020). They may occur in the Kujawsko-Pomorskie, Lubelskie, Łódzkie, Mazowieckie, Podlaskie, Śląskie, Świętokrzyskie and Zachodniopomorskie voivodeships.

According to the “Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons” (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987), that establishes parameter limits that defines a deposit, exploitable quartz sand deposit requires a minimum thickness of 2 m with a ratio of overburden to deposit series not exceeding 0.5, a maximum silt content of 5% and a minimum quartz grain content of 90%.

It should be stated that accuracy of prospecting and exploration of these sand deposits has been sufficient. The deposits are fairly evenly distributed throughout the whole area of the country, except for the Carpathians. In the latter region, resources of sand deposits (especially good-quality quartz sand) occur in insufficient amounts to supply the local demand (Plate 8).

In 2020, anticipated economic resources of **quartz sand for the production of cellular concrete** amounted to 137.09 Mm^3 (246.76 Mt – recalculated according to 1.8 factor) (Tab. 11.23.1). The resources have been fluctuating in a range of 120–145 Mt for the last 30 years, with a slightly increasing tendency (Fig. 11.23.1). The number of deposits

Table 11.23.1. Quartz sand for the production of cellular concrete resources [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	60	137.09	49.24	87.85	1.62	13.68
Including resources of exploited deposits						
Deposits of operating mines	9	21.87	18.67	3.20	0.27	10.33
Including resources of non-exploited deposits						
TOTAL	40	105.34	20.70	84.65	0.82	1.44
1. Deposits covered by detailed exploration	16	26.59	20.70	5.89	0.34	1.44
2. Deposits covered by preliminary exploration	24	78.75	0.00	78.75	0.47	–
Including abandoned deposits						
Abandoned deposits	11	9.88	9.88	–	0.53	1.90

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

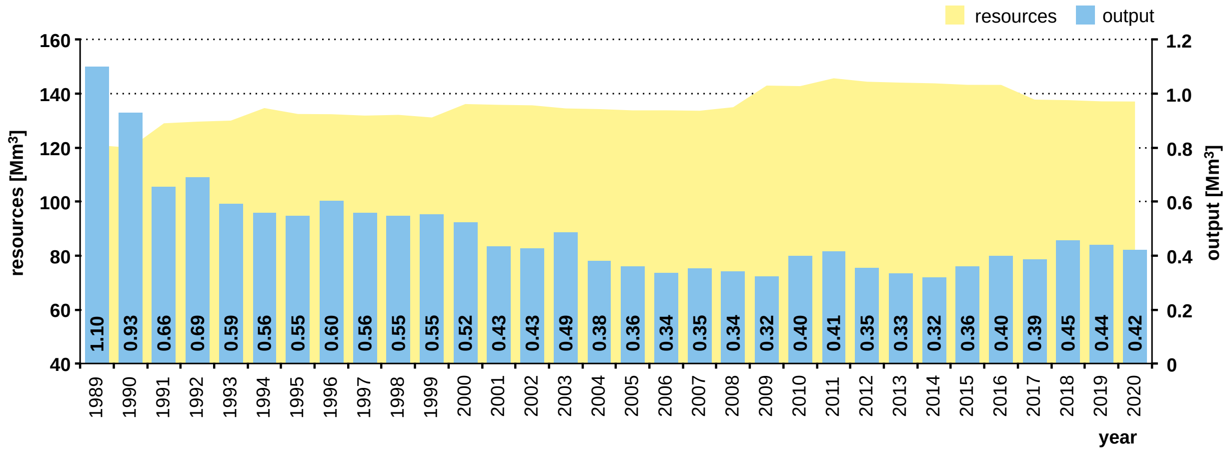


Figure 11.23.1. Quartz sand for the production of cellular concrete – anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Table 11.23.2. Quartz sand for the production of sand-lime brick resources [Mm^3]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**106**	**262.52**	**135.03**	**127.49**	**6.34**	**21.49**
Including resources of exploited deposits						
TOTAL	23	47.65	42.12	5.53	–	21.28
1. Deposits of operating mines	14	31.96	26.43	5.53	–	10.67
2. Deposits exploited temporarily	9	15.69	15.69	–	–	10.62
Including resources of non-exploited deposits						
TOTAL	50	177.87	60.87	117.00	2.75	–
1. Deposits covered by detailed exploration	28	62.30	60.87	1.43	2.75	–
2. Deposits covered by preliminary exploration	22	115.57	0.00	115.57	–	–
Including abandoned deposits						
Abandoned deposits	33	36.99	32.04	4.95	3.60	0.21

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

increased from 47 in 1989 to 60 by 2020. Significant increases in resources were recorded in the following years: 1991 (2 new deposits), 1994 (4 new deposits), 2000 (1 new deposit), 2009 (approval of a new documentation of an already documented deposit), 2011 (1 new deposit and approval of a new documentation of 2 already documented deposits). Economic resources within exploited deposits amounted to 13.68 Mm^3 in 2020 (Tab. 11.23.1).

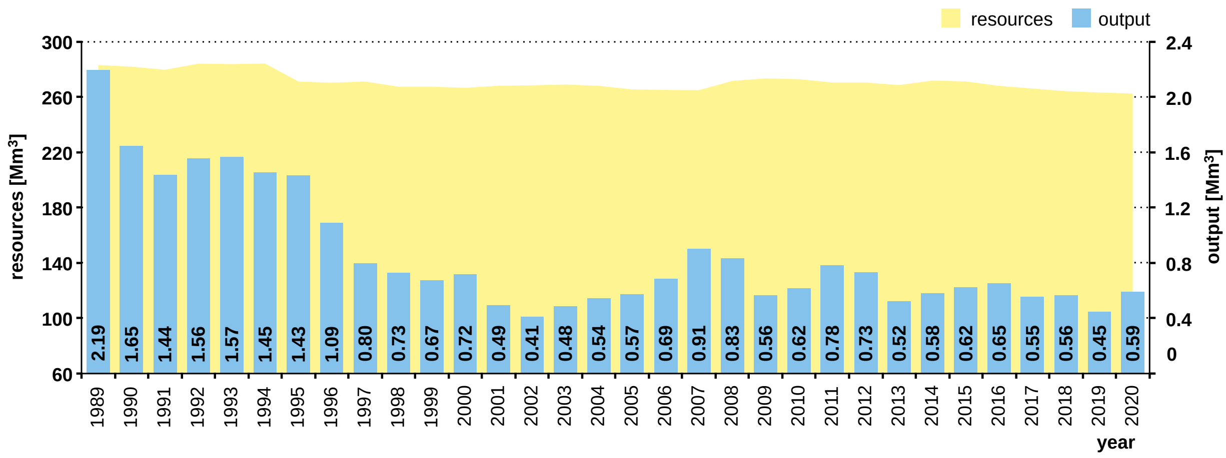


Figure 11.23.2. Quartz sand for the production of sand-lime brick – anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

Despite the increasing base of resources, exploitation of quartz sand for the production of cellular concrete was decreasing significantly in 1990's from more than 1 Mm^3 in 1989 (17 exploited deposits) to about 0.5 Mm^3 in 1999 (9 exploited deposits). Later output had been fluctuating within a range of 0.3–0.5 Mm^3 and amounted to 0.42 Mm^3 in 2020 (Fig. 11.23.1). It was the result of a crisis in the building materials industry and production limitations, and due to the fact that other raw materials, such as fly ash from power stations or building sand, were used for cellular concrete production. Nevertheless, Poland remains the European leader in the production of articles made of cellular concrete. The biggest output in 2020 came from the Studzienice deposit in the Pomorskie voivodeship (0.1 Mm^3), whereas the production from other exploited deposits remained at about 0.03–0.05 Mm^3.

For the last 30 years, anticipated economic resources of **quartz sand for the production of sand-lime brick** have been slightly decreasing by a few percentages and amounted to 262.52 Mm^3 (472.54 Mt) in 2020 (Tab. 11.23.2). There are 47.65 Mm^3 within 23 exploited deposits and that volume account for 18% of total resources (Fig. 11.23.2). Economic resources amounted to 21.49 Mm^3.

Exploitation of quartz sand for the production of sand-lime brick were decreasing from over 2 Mm^3 in 1989 (42 exploited deposits), to about 0.7 Mm^3 in 1999 (38 exploited deposits). Later output has been fluctuating in a range of about 0.4–0.9 Mm^3, and amounted to 0.59 Mm^3 in 2020. Almost 40% of the output in 2020 came from the Mazowieckie voivodeship, mostly from the Augustowo deposit near Ciechanów (0.17 Mm^3). Production depends on demand for building materials. This raw material is utilized locally, in production plants located in the neighborhood of quartz sand deposits.

In 2020, total anticipated economic resources of quartz sand for the production of cellular concrete and sand-lime brick amounted to 399.61 Mm^3 (719.30 Mt).

11.24. Refractory clays

M. Tymiński

Kaolinite clays, also referred to as refractory clays, are indispensable raw materials for the production of fire-resistant aluminosilicate materials. They are also used for the production of ceramic tiles and sanitary articles. Such clays can occur as the result of washing down of outcropping and near-surface kaolinized rocks and redeposition of kaolinite, connected with a separation of quartz grains and a marked improvement of fire resistance properties of this raw material.

Basic components of the refractory clays are kaolinite clays, characterized by high plasticity and with an ability

Table 11.24.1. Refractory clays resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**16**	**54.08**	**53.41**	**0.67**	**110.26**	**1.82**
Including resources of exploited deposits						
Deposits of operating mines	2	6.30	6.11	0.18	–	1.82
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	5	43.39	43.24	0.15	106.02	–
Including abandoned deposits						
Abandoned deposits	9	4.40	4.06	0.34	4.24	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

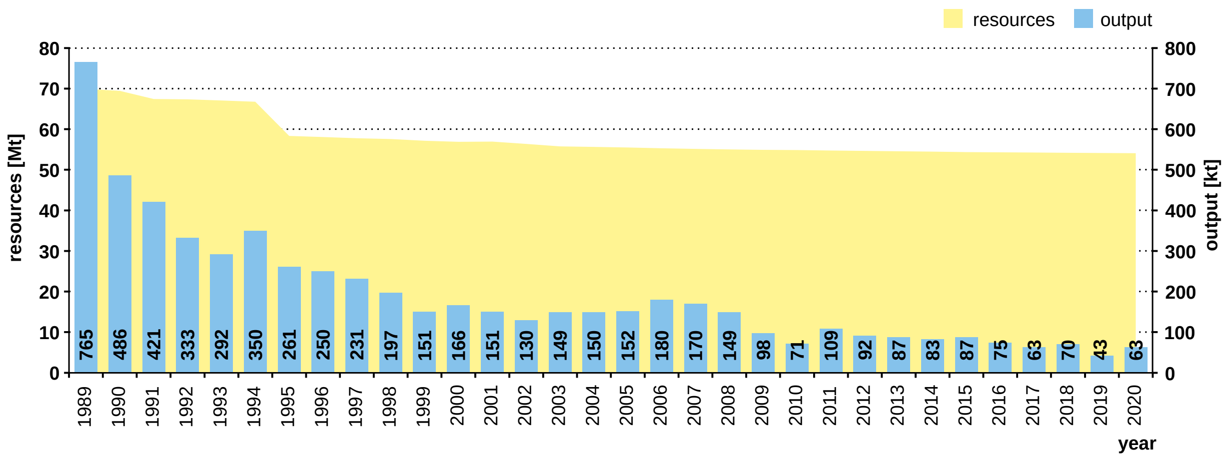


Figure 11.24.1. Refractory clays anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

to form a ceramic body with high mechanical strength. The fire resistance of such clays should be a minimum of 1,650°C.

In Poland, deposits of refractory clays occur in the Lower Silesian region and in the north-eastern part of the Holy Cross Mts. (Plate 7). Deposits exploited in 2020 – Rusko-Jaroszów and Borkowice-Radestów – the first situated in the Świdnicki County, the Dolnośląskie voivodeship, and the second in the Przysusuki County, the Mazowieckie voivodeship. Other refractory clay deposits are not being exploited at present. Output production from the Rusko-Jaroszów deposit has been continued for years, whereas an exploitation concession for the Borkowice-Radestów deposit was issued in 2020.

In the latest edition of "The balance of prospective mineral resources of Poland", an assessment of prospective resources of refractory clays in Poland was updated (Galos, 2020b). Main criteria adopted for determining refractory clays deposits were: minimum deposit thickness (1 m) and a maximum overburden to deposit thickness ratio (N/Z < 2), in addition the qualitative raw material parameters: fire resistance (minimum of 161 sP) and a >0.063 mm grain content (maximum of 10%). Taking these parameters into account, prognostic resources of refractory clays were assessed to amount to 56.90 Mt (within the area of Udanin in the Dolnośląskie voivodeship).

As of the end of 2020, anticipated economic resources of refractory clays amounted to 54.08 Mt (Tab. 11.24.1). The anticipated economic resources covered by detailed exploration (in the A+B, and C_1 categories) amounted to 53.41 Mt. They accounted for 98.76% of total anticipated economic resources. Economic resources of refractory clays amounted to 1.82 Mt, accounting for 1.94% of total anticipated economic resources and 28.89% of the anticipated economic resources within exploited deposits. The economic resources significantly increased in comparison with the previous year – by 0.77 Mt (73.33%) as a result of a deposit development plan approval for Borkowice-Radestów (+0.82 Mt) and exploitation.

The anticipated economic resources of refractory clays in the 1989–2020 period decreased from 69.92 Mt to 54.08 Mt – that is by 15.84 Mt (–22.65%) in total (Fig. 11.24.1). The resources volume has been systematically declining in the whole presented period with the most significant decrease recorded in 1995. The resources decreased by 8.43 Mt due to the reclassification of resources in the Rusko-Jaroszów deposit. Other decreases were caused mainly by exploitation and losses. Within the last 5 years, the resources declined from 54.31 Mt in 2016, to 54.08 Mt in 2020. The decrease in annual resources resulted from exploitation of the Rusko-Jaroszów deposit. In 2020, the resources decreased by about 0.06 Mt (–0.11%) in comparison with 2019. The output was fluctuating within a range of 43–75 kt. During the analyzed period the biggest decrease was recorded in 2019 – from 69.88 to 42.88 kt (by 38.57%). In 2020, the output of refractory clays amounted to 63.34 kt and increased by 20.46 kt (47.71%) in comparison with the previous year. Exploitation from the Rusko-Jaroszów deposit grew by 12.46 kt (29.06%) and the exploitation from the Borkowice-Radestów deposit started (8 kt). The exploited raw material may be used without any processing or after firing, when it becomes “fired clay”.

11.25. Refractory quartzite

A. Malon

Refractory quartzite is used in metallurgy for making ferroalloys, and in the insulating materials industry for making siliceous fire-proof materials. Quartzite is a compact hard metamorphic rock, which was originally sandstone. Pure quartzite is recrystallized sandstone with siliceous cement, often with an SiO_2 content over 99% and almost exclusively built of quartz grains cemented with silica. In the insulating materials industry, the name of “fire-proof quartzite” is used for both pure quartzite and other silica-rich rocks such as quartzitic sandstone and schist. According to the GML obliging, as of the 1st of January, 2012, there are “parameter limits that define a deposit and its boundaries” for quartzites, quartzitic sandstone and schist:

- minimum deposit thickness – 5 m,
- maximum proportion of overburden thickness in relation to deposit thickness – 0.5,
- minimum SiO_2 content – 95%,
- maximum $Fe_2O_3 + TiO_2$ + alkali content – 1.0%.

In Poland, quartzite deposits occur in 2 regions: the Lower Silesia region and the Holy Cross Mts. (Plate 7). In the Lower Silesia they are formed of irregular quartzitic layers and lenses dated at the Neogene. The majority of these sites was explored and exploited in the past. Actually only 2 abandoned deposits still comprise some relict resources, but 10 deposits were removed from the deposit registry of Poland. Only 2 quartzite deposits from Kowalskie and Milików still remain to be developed in this region. Quartzite deposits occurring in the Holy Cross Mts. are formed by quartzite intercalations in Paleozoic clay and clay schist. The deposits were explored in the 1950’s, but only 1 of them (Bukowa Góra) is still being exploited. The raw material of the said deposit has not been classified as refractory quartzite, but as quartzitic sandstone. Therefore, the Bukowa Góra deposit is also discussed in the section on dimension and crushed stone. The prospective resources of quartzite, together with quartzitic schist, are assessed to amount to

Table 11.25.1. Refractory quartzite resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	$A+B+C_1$	C_2+D		
TOTAL RESOURCES	**8**	**6.59**	**3.57**	**3.02**	**3.96**	**–**
Including resources of non-exploited deposits						
TOTAL	6	5.93	3.21	2.72	3.84	–
1. Deposits covered by detailed exploration	5	5.23	3.21	2.02	3.84	–
2. Deposits covered by preliminary exploration	1	0.70	–	0.70	–	–
Including abandoned deposits						
Abandoned deposits	2	0.66	0.36	0.30	0.12	–

27.04 Mt and occur in the Dolnośląskie and Świętokrzyskie voivodeships (Brzeziński, Galos, 2020).

Anticipated economic resources of the refractory quartzite amounted to 6.59 Mt (Tab. 11.25.1). There were 10 abandoned, exhausted deposits removed from "The balance…" in 2015. In the 2016–2020 period, the resources remained steady at around 6.59 Mt.

No output of refractory quartzite was registered in 2016–2020, because the Bukowa Góra deposit was the only deposit exploited for refractory quartzite.

11.26. Sand and gravel

W. Miśkiewicz, D. Brzeziński, A. Kalinowska, J. Stawierej

There are 2 major groups of natural sandy-gravelly aggregates differentiated: the coarse aggregate group, comprising gravel and sand-gravel mix (sandy-gravelly aggregate), and the fine aggregate group – comprising sand (sandy aggregate). Natural aggregates are used mainly in building (concrete fill) and road construction (embankment and highway fill and road surfacing).

The largest demand is for natural coarse aggregates, especially as distribution of their resources is far from uniform throughout Poland. Resources of natural coarse aggregates are generally small in the central parts of the country (Plate 8), and are not sufficient to supply local demand.

The bulk of Polish natural aggregate deposits are Quaternary in age. The share of deposits Pliocene, Miocene and Liassic in age is subordinate.

The quality of raw material (especially its homogeneity) depends largely on a genetic type of a given deposit. Fluvial deposits clearly predominate in the Carpathian-Sudetic zone (southern Poland). In the Sudety Mts., the most common deposits are the Pleistocene sandy-gravelly higher terraces, composed mainly of detritus from sandstone and crystalline rocks. In turn, in the Carpathian region, the raw material basis mainly comprises gravelly and sandy-gravelly deposits occurring on floodplain terraces, as well as valley side terraces rising above flood plains. The Carpathian deposits are characterized by a predominance of material coming from the disintegration of flysch rocks, except for those of the Dunajec River valley, which indicate a fairly high contribution of crystalline rocks from the Tatry Mts.

In northern and central Poland (the Polish Lowland region), the most important deposits are of glacial (terminal moraine accumulation platforms) and fluvioglacial (outwash plains and eskers) origin and result from river accumulation. Deposits in the northern part of this area represent gravelly-sandy accumulations, mainly comprising the Scandinavian material – debris of crystalline rocks and limestone with an admixture of quartz and sandstone. In the central and southern parts of this region, the deposits are mainly formed of sandy sediments with a significant share of debris from local rocks.

According to the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987), excluding hydrocarbon fields, establishing parameter limits that define a deposit and its borders:

- a sand deposit with sand content above 75% should be characterized by: thickness no less than 2 m, a ratio of overburden to deposit series not higher than 0.3 and a content of the silt fraction below 10%;
- a gravelly, gravelly-sandy and sandy-gravelly deposit with sand content below 75% should be characterized by: thickness not smaller than 2 m, with a ratio of overburden to deposit series not higher than 1.0 and a content of the silt fraction below 15%.

As of the end of 2020, anticipated economic resources of natural aggregates totaled 19,960.61 Mt (Tab. 11.26.1). The resources increased by 217.95 Mt (that is by 1.09%) in relation to the previous year (Miśkiewicz *et al.*, 2021). The natural sandy-gravelly aggregate has been documented under 4 subtypes: sand, sand with gravel, gravel, loamy and silty sand. The sand resources of with a sand content above 75% amount to 9,439.01 Mt (an increase by 469.37 Mt in comparison with 2019), of which 2,718.50 Mt are within exploited deposits. The gravelly-sandy and sandy-gravelly aggregate resources with a sand content between 30 and 75% amount to 9,495.07 Mt (a decrease by 251.71 Mt). The gravel resources (with a sand content <30%) amount to 989.39 Mt (a decrease by 4.85 Mt), and the loamy and silty sand resources amount to 37.14 Mt (an increase by 5.15 Mt).

The voivodeships with the largest documented resources are: Dolnośląskie (2,320 Mt), Małopolskie (1,797 Mt), Podlaskie (1,690 Mt), Opolskie (1,433 Mt), Mazowieckie (1,340 Mt) and Podkarpackie (1,334 Mt). The number of deposits, amounts of resources and output in regard to resources are presented on the pie-charts in Figure 11.26.1.

In Poland, there are 813 identified (Kozłowska *et al.*, 2020) prognostic areas with the total area of sandy-gravelly aggregate exceeding 72 kha and with resources amounting to 13.05 bnt; and 5,717 preliminarily designated (on a basis of geological presumptions) prospective areas with a total area exceeding 600 kha. In comparison with the previous publication of this type, the prognostic resources increased by more than 5.3 bnt documented within about 200 new areas. The most exploration opportunities occured in the following voivodeships: Pomorskie (2,105 Mt), Mazowieckie (1,987 Mt), Małopolskie (1,405 Mt) and Lubelskie (1,064 Mt). The smallest possibilities are connected with such voivodeships as: Warmińsko-Mazurskie (186 Mt), Lubuskie (234 Mt), Podkarpackie (317 Mt) and Opolskie (335 Mt).

The frequency of occurrence of various size deposits of sand and gravel in Poland is shown in Figure 11.26.2.

In 2020, output of sand and gravel from deposits amounted to 180.24 Mt. In comparison with the previous year it fell by 2.57 Mt that is by 1.4%. Exploitation decreased in 10 out of 16 voivodeships. The year 2020 was the second consecutive with a decrease in output. In 2020, more than 133.9 Mt (74%) of exploited raw materials came from deposits with resources in a range between 0.5 and 20 Mt, whereas from deposits with resources up to 0.1 Mt produced about 5.6 Mt (3.1%) of raw materials.

Companies producing natural aggregate for the Polish market are operating individually or are associated in groups. Exploitation is being carried out in one or two plants, and in the case of the biggest companies even in dozen or so plants. More than 1,300 companies (the most numerous in 2020) exploited up to 50 kt of raw material. Their total contribution in domestic output was 11% (about 20 Mt). The biggest contribution (about 72 Mt), that is almost 40% in total domestic output, was made by a group of 20 concession holders. Every single company from this group individually exploited at least 1 Mt each, whereas the largest companies exploited more than 5 Mt of the sandy-gravelly aggregate.

Anticipated economic resources of sand and gravel between 1989 and 2006 oscillated within a range of 11.7–14.8 bnt, whereas in the 1993–2006 period, it remained steady at about 14.1–14.8 bnt. The size of resources has been increasing since 1989 in general, except for minor

Table 11.26.1. Sand and gravel resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**10,672**	**19,960.61**	**12,207.76**	**7,752.85**	**409.62**	**4,301.75**
Including:						
Sand		9,439.01	6,380.96	3,058.05	119.38	2,228.07
Sand and gravel		9,495.07	5,393.54	4,101.53	274.80	1,957.58
Gravel		989.39	398.64	590.75	11.62	99.84
Loamy and silty sand		37.14	34.62	2.53	3.81	16.24
Including resources of exploited deposits						
TOTAL	3,891	6,132.59	5,363.67	768.92	64.56	3,626.75
Including:						
Sand		2,718.50	2,591.99	126.51	36.01	1,771.83
Sand and gravel		3,100.87	2,522.18	578.69	25.42	1,744.47
Gravel		286.20	225.01	61.19	2.95	95.99
Loamy and silty sand		27.02	24.49	2.53	0.18	14.47
1. Deposits of operating mines	2,598	4,451.47	3,982.47	469.00	45.60	2,692.34
Including:						
Sand		1,928.18	1,839.14	89.05	27.15	1,278.74
Sand and gravel		2,252.06	1,925.24	326.82	15.40	1,322.19
Gravel		244.35	193.68	50.66	2.95	77.04
Loamy and silty sand		26.88	24.41	2.47	0.10	14.38
2. Deposits exploited temporarily	1,293	1,681.11	1,381.20	299.92	18.96	934.41
Including:						
Sand		790.31	752.85	37.46	8.86	493.09
Sand and gravel		848.81	596.94	251.87	10.02	422.28
Gravel		41.86	31.33	10.53	–	18.95
Loamy and silty sand		0.13	0.08	0.05	0.08	0.09
Including resources of non-exploited deposits						
TOTAL	3,911	12,106.15	5,492.68	6,613.47	238.61	670.48
Including::						
Sand		5,855.45	3,049.44	2,806.01	66.74	452.54
Sand and gravel		5,560.43	2,277.67	3,282.76	165.71	212.30
Gravel		681.47	156.78	524.69	5.33	3.86
Loamy and silty sand		8.79	8.79	-	0.83	1.78

Table 11.26.1. Cont.

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
1. Deposits covered by detailed exploration	3,559	5,852.94	5,476.92	376.02	141.94	670.47
Including:						
Sand		3,101.12	3,043.02	58.10	51.73	452.53
Sand and gravel		2,580.09	2,268.33	311.76	86.51	212.30
Gravel		162.93	156.78	6.16	2.87	3.86
Loamy and silty sand		8.79	8.79	–	0.83	1.78
2. Deposits covered by preliminary exploration	352	6,253.21	15.77	6,237.44	96.67	0.02
Including:						
Sand		2,754.33	6.42	2,747.91	15.00	0.02
Sand and gravel		2,980.34	9.34	2,971.00	79.20	–
Gravel		518.54	0.00	518.54	2.46	–
Including abandoned deposits						
Abandoned deposits	2,870	1,721.88	1,351.41	370.47	106.44	4.51
Including:						
Sand		865.07	739.54	125.53	16.63	3.70
Sand and gravel		833.76	593.68	240.08	83.67	0.81
Gravel		21.71	16.85	4.86	3.34	–
Loamy and silty sand		1.33	1.33	–	2.80	–

The key for comparison and estimation of mineral resources from Polish mineral classification into UNFC Update 2019 is presented on page 40

decreases in 1995 and at the beginning of 21st century. By 2020 the resources have increased to about 19.96 bnt that is by about 26% (Fig. 11.26.3). A significant increase – in spite of intensive exploitation – was recorded in the 2007–2020 period. Since the last edition of "Mineral Resources of Poland" (Szamałek *et al.*, eds., 2017) there was an increase in resources by 1.32 bnt. The resources increased in almost every voivodeship, but most significantly in: the Pomorskie (235.5 Mt), Wielkopolskie (168.1 Mt), and Podlaskie (166.6 Mt) voivodeships; the resources decreased in the Małopolskie voivodeship (–48.7 Mt), and the Baltic Sea (–5.8 Mt). The resources of particular sub-types changed as follows: sand (+1,501.4 Mt), sand with gravel (–317.6 Mt), gravel (+129.1 Mt), loamy and silty sand (+8.32 Mt). Increases in resources, in spite of significant exploitation, resulted from an intensive interest in the exploitation of natural sandy-gravelly aggregate. A large demand for this raw material – for road building, housing construction and industrial construction – resulted in prospecting and exploration of new raw material sources. It is visible in every single area where large investments are planned and within urban centers. For almost 30 years the increasing tendency of output has been recorded with periodic decreases. Such tendencies coincided with economic trends and political-economic incidents. The most important were the Polish accession to the EU, the organization the 2012 UEFA European Championship and – in the meantime – economic crises in 2000–2001 and 2008–2009.

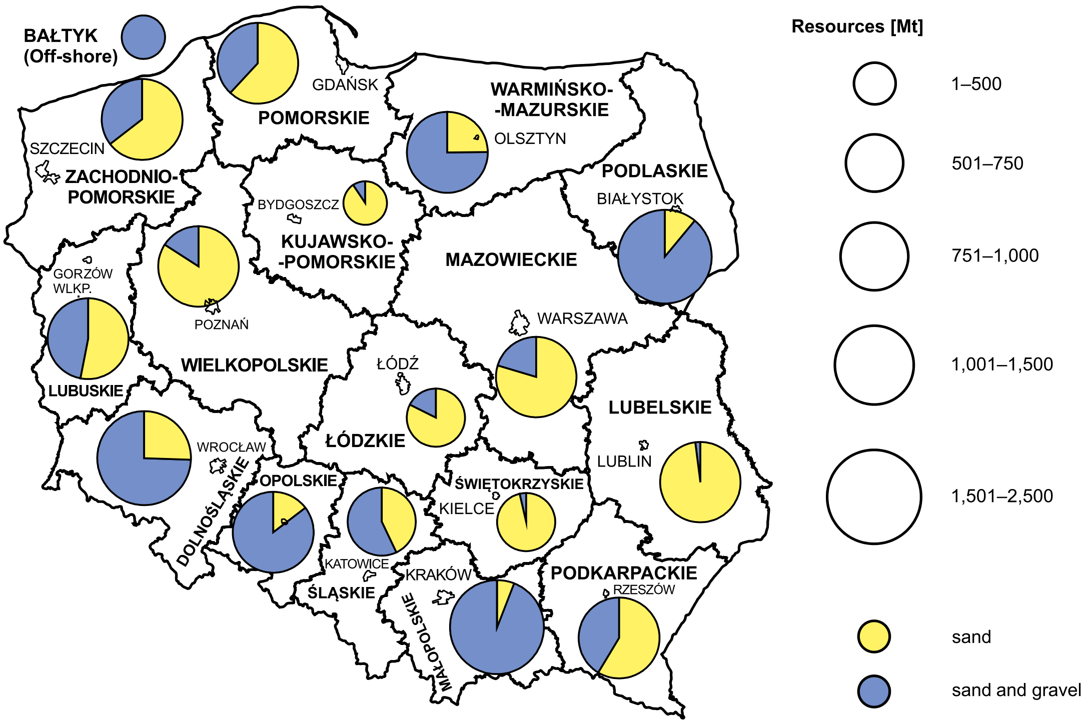


Figure 11.26.1. Distribution of sand and gravel resources in 2020

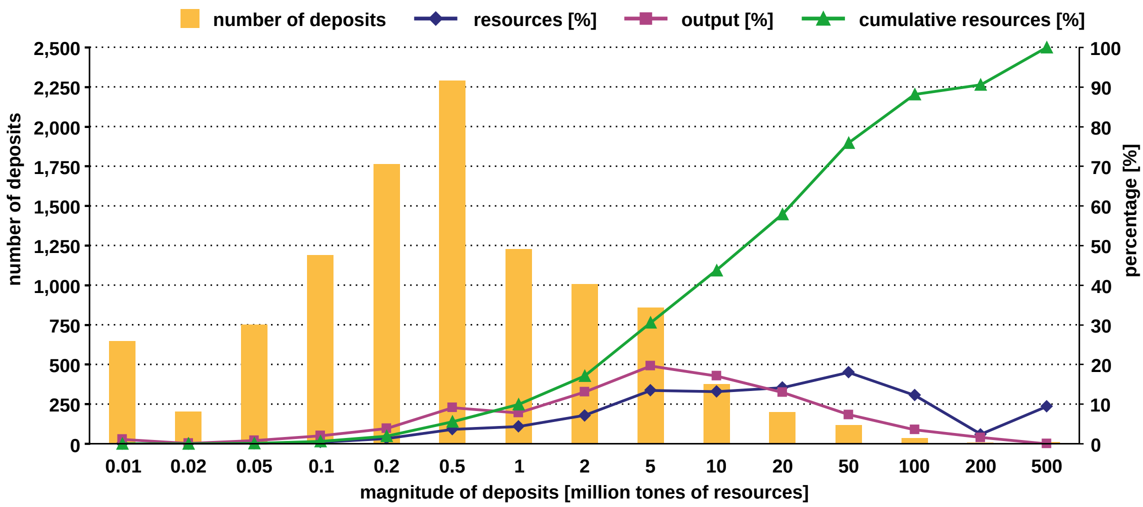


Figure 11.26.2. Frequency of the size of resources in sand and gravel deposits in 2020

By investing large financial means into building investments, together with an improved economic condition, resulted in growing exploitation tendencies in the 2015–2018 period – output amounting to about 200 Mt. In the 2016–2020 period, there were 919.5 Mt of the raw material exploited. The majority of it came from the following voivodeships: Podlaskie (119.2 Mt), Pomorskie (87.8 Mt), Warmińsko-Mazurskie (83.2 Mt) and Mazowieckie (82.9 Mt). The previous 2 years brought a domestic output decrease to 180.24 Mt in 2020. In most industry branches using natural sandy-gravelly materials, for example the infrastructure construction, where in the last few years there were many central investments finalized, the construction of housing and industrial construction, was all experienced a decrease in demand. In 2020, the declining tendency was a result of economic slowdown or disturbance due to a decrease in building-mounting production, a reduction of public tenders for

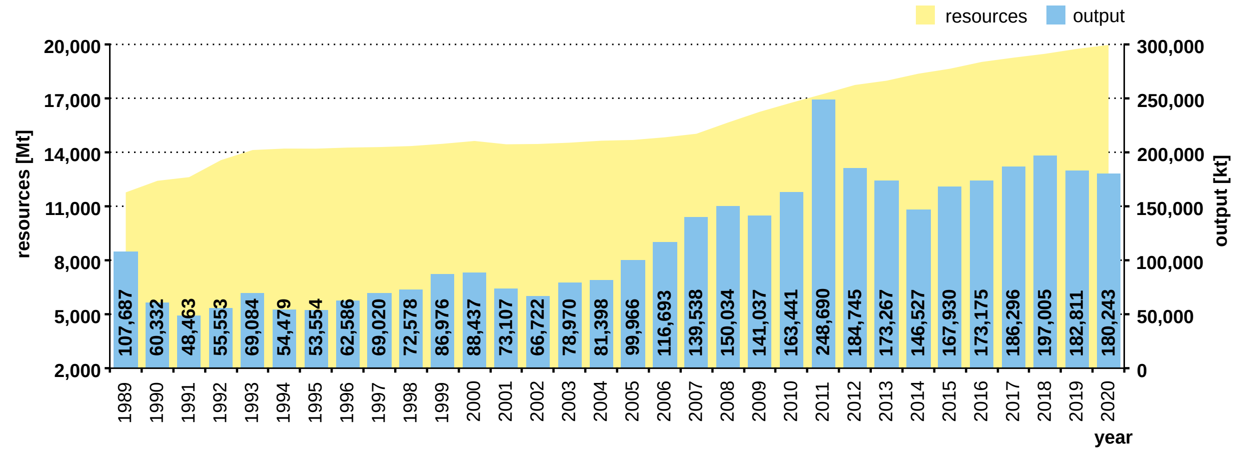


Figure 11.26.3. Sand and gravel anticipated economic resources and output in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

building roads and the COVID-19 pandemic. Currently, central investments are the main factor driving an increase in exploitation – there are continued and planned investments of the S6, S7, S10, S11, S16, S17, S19 and S74 motorways, whereas an expansion of the A2 and A4 motorways is planned in the near future (Generalna Dyrekcja Dróg i Autostrad, 2021 – https://www.gov.pl/web/gddkia/mapa-stanu-budowy-drog3).

11.27. Sand with heavy minerals

S.Z. Mikulski

Sand with placer heavy minerals are recognized and documented in the Baltic Sea – Zatoka Pomorska area (Polish Economic Zone of the Baltic Sea).

The share of heavy minerals in sand is variable. In the sediment layer from the sea-bottom, from its surface to a depth of 0.5 m, the heavy minerals content is between 1.4 and 21.7% (on average 4.4–4.5%). In the sand layer for depths between 0.5 and 1.0 m below the sea-bottom, content of heavy minerals varies from 2 up to 4.2% (on average 2.5–3.3%). As a marginal criteria for determining a deposit, there was a boundary value of minimum 2% heavy minerals content accepted. The identified heavy minerals of the Ławica Odrzana deposit are: ilmenite ($FeTiO_3$), rutile (TiO_2), zircon ($ZrSiO_4$), as well as garnet $(Fe, Ca, Mg, Mn)_3(Al, Fe, Cr)_2(SiO_4)_3$. The contribution of individual minerals in overall mass of the heavy minerals is equal to: ilmenite – 31%, zircon – 5%, leucoxene – 4%, rutile – 4%, garnet – 32%.

In the zircon concentrate from the Ławica Odrzana sand, the rare-earth elements content is as follows: Ce – 3.9 g/kg, La – 1.9 g/kg, Nd – 1.7 g/kg, Pd, Y, Gd and Sa within the range of 0.2–0.5 g/kg; whereas in the zircon concentrate from the Ławica Słupska sand, the following contents were indicated: Ce – 3.9 g/kg; La – 1.9 g/kg; Nd – 0.96 g/kg.

The heavy minerals from the Ławica Odrzana deposit could be used for the production of pigments and coatings, manufacturing of high strength steel, for biomedical engineering, ceramics and glass, in the nuclear power industry and in the manufacture of abrasive and fibers. Remaining after the separation of heavy minerals, silica sand could be used in the glass industry, in the manufacture of molding sand and in the construction industry.

11.28. Vein quartz

A. Malon

Quartz (SiO_2) is the most common mineral occurring in igneous, metamorphic and sedimentary rocks. Under favorable crystallization conditions, such as in voids of igneous or metamorphic rock, it forms sharp-pointed, hexagonal, long and slender crystals which are widely used as a popular ornamental stone and also a gemstone in jewellery. Depending on the admixture of coloring oxides, several varieties of these gemstones are differentiated: clear and colorless rock crystal, green to yellow-green praseolite, yellow to orange citrine, pink to rose pink quartz, purple to violet amethyst, brown to gray smoky quartz and black morion.

Quartz also forms veins and lenses in metamorphic and igneous rock. Quartz vein deposits originate as a result of hydrothermal activity as an infill of open fissures and fractures intersecting through a given rock massif. Quartz infills are characterized by a high content of silica (SiO_2) and a low content of coloring oxides (Fe_2O_3 and TiO_2). Thus composed quartz crystals occur due to their piezoelectric properties, as basic raw materials for electronics. It is also used in production of ceramics, fire-proof materials, enamel, metallurgy, optics and the production of jewelry. Its purest varieties are used in the manufacture of high-quality glass and are also the source of high-quality quartz powder and grits to production of ferrosilicon. The demand for quartz has decreased significantly in the last years in Poland, especially for the needs of the: ceramic industry, fire-proof materials and metallurgy.

In Poland, quartz veins mainly occur in Precambrian and Paleozoic crystalline rock massifs of the Sudety Mts. (Plate 6). The deposits are characterized by a high variability in thickness and quality of raw material, as well as a general high dip angle of the veins and lenses. Prognostic resources of vein quartz are assessed to amount to 2.87 Mt and prospective resources to 1.33 Mt (Wołkowicz, Sroga, 2020).

Anticipated economic resources of vein quartz have not changed since 2015 and amounted to 5.61 Mt in 2020 (Tab. 11.28.1). The largest anticipated economic resources hitherto discovered amounted to 3.3 Mt in the Stanisław deposit located south-west of Jelenia Góra, and 1.5 Mt in the Krasków deposit in the vicinity of Świdnica, in the Sudety Mts. (Plate 6).

None of the vein quartz deposits in Poland are being currently exploited. Output from the last exploited deposit (Taczalin) was suspended in 2015.

Table 11.28.1. Vein quartz resources [Mt]

	Number of deposits	Geological resources in place				Economic resources in place as a part of anticipated economic resources
		Anticipated economic			Anticipated sub-economic	
		Total	A+B+C_1	C_2+D		
TOTAL RESOURCES	**6**	**5.61**	**3.72**	**1.89**	**0.35**	**1.35**
Including resources of non-exploited deposits						
Deposits covered by detailed exploration	2	0.28	0.22	0.06	–	–
Including abandoned deposits						
Abandoned deposits	4	5.33	3.51	1.83	0.35	1.35

12. Brines, curative and thermal water

J. Sokołowski, L. Skrzypczyk

According to the GML (dated the 9th of June, 2011 – Journal of Laws of 2021, Item 1420 – unified text), groundwater is considered as a mineral resource (brines, curative or thermal water) solely on the basis of their specific physical and chemical properties.

Brine: groundwater with total solid minerals dissolved at least to 35 g/dm³. When considering exploitation, the only deposit that is classified as brine is the deposit in Łapczyca in the Małopolskie voivodeship. The brine occurs in the Miocene sandstone formation, and is used for therapeutic and bath salt production. Groundwaters of similar composition (strongly mineralized waters of the Cl-Na or Cl-Na-Ca types, with higher amounts of iodine ions) are common in the area of Polish Lowland. They occur in very deep formations, at a depth of a few thousand meters.

Curative water: according to GML, curative water is groundwater with no chemical and microbiological contamination, with a natural diversity of physical and chemical properties, meeting at least one of the following requirements:

- total dissolved solid mineral content at least 1,000 mg/dm³;
- ferrous ion content – at least 10 mg/dm³ (ferruginous waters);
- fluoride ion content – at least 2 mg/dm³ (fluoride waters);
- iodine ion content – at least 1 mg/dm³ (iodide waters);
- bivalent sulfur ion content – at least 1 mg/dm³ (sulfide waters);
- metasilicic acid content – at least 70 mg/dm³ (silica waters);
- radon content – at least 74 Bq (radon waters);
- carbon dioxide content – at least 250 mg/dm³ (250–999 mg/dm³ carbonic acid waters, ≥1,000 mg/dm³ carbonated water).

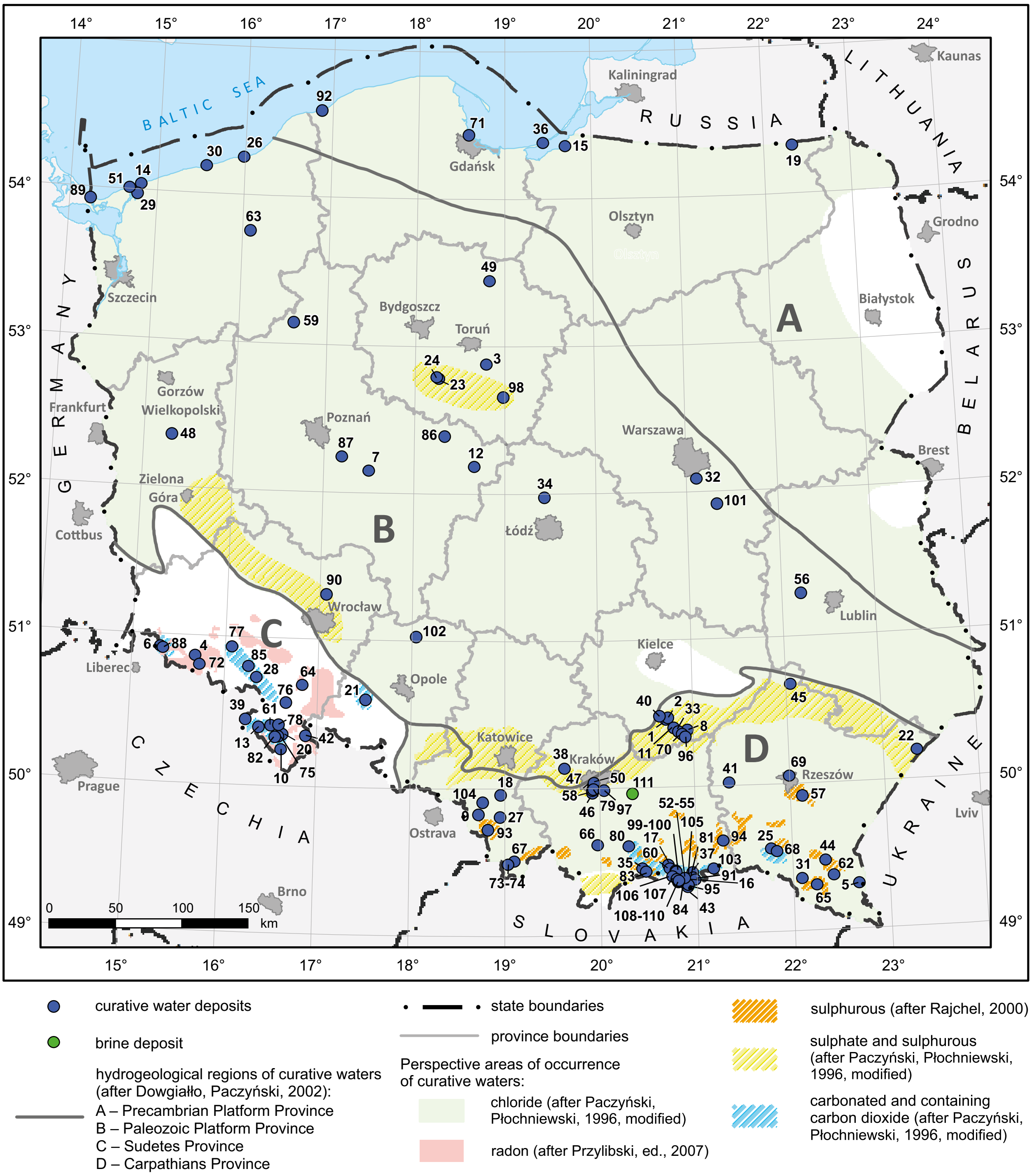
Most of curative waters – over 70 % occur in health resorts and towns of southern Poland, in the Sudetes and the Carpathian region (including the Carpathian Depression). The rest of the deposits occur in Western Pomerania and in the Polish Lowland. Curative waters are used mainly for balneotherapy (baths, inhalations, drinking treatment) and bottling purposes (i.e. Krynica-Zdrój, Muszyna, Piwniczna-Zdrój, Wysowa-Zdrój, Polanica-Zdrój, Ciechocinek, Rymanów-Zdrój, Gorzanów, Szczawnica, Szczawno-Zdrój), but also for salt, lye and mud production, pharmaceutical specimens and medicines (i.e. Ciechocinek, Dębowiec, Iwonicz-Zdrój, Rabka-Zdrój, Kołobrzeg, Zabłocie, Busko-Zdrój, Goczałkowice-Zdrój). Moreover, in Krynica-Zdrój and Duszniki-Zdrój, natural carbon dioxide is obtained from curative waters.

Mineralized and specific groundwater (with a total dissolved solid minerals content over 1,000 mg/dm³, (Dowgiałło *et al.*, eds., 2002), not considered as curative, occur commonly in Poland at various depths, more often deeper than ordinary waters. The variety of chemical composition of these waters (Fig. 12.1) is caused by the diversity of geological and hydrogeological conditions. The following types are distinguished:

- strongly mineralized chloride waters, mainly of the Cl-Na, (I) type;
- bicarbonate waters, mainly of the HCO_3-Ca-(Mg), (Fe) type;
- specific waters of various mineralization: Fe, F, I, S, H_2SiO_3, Rn, CO_2, thermal.

Thermal water: groundwater in all geological units having a minimum temperature of 20°C at the outflow, excluding drainage waters from mining areas. In Poland, it occurs in the area of the Polish Lowland, within large reservoirs of regional importance, as well as in the Carpathians and Sudetes (Fig. 12.2).

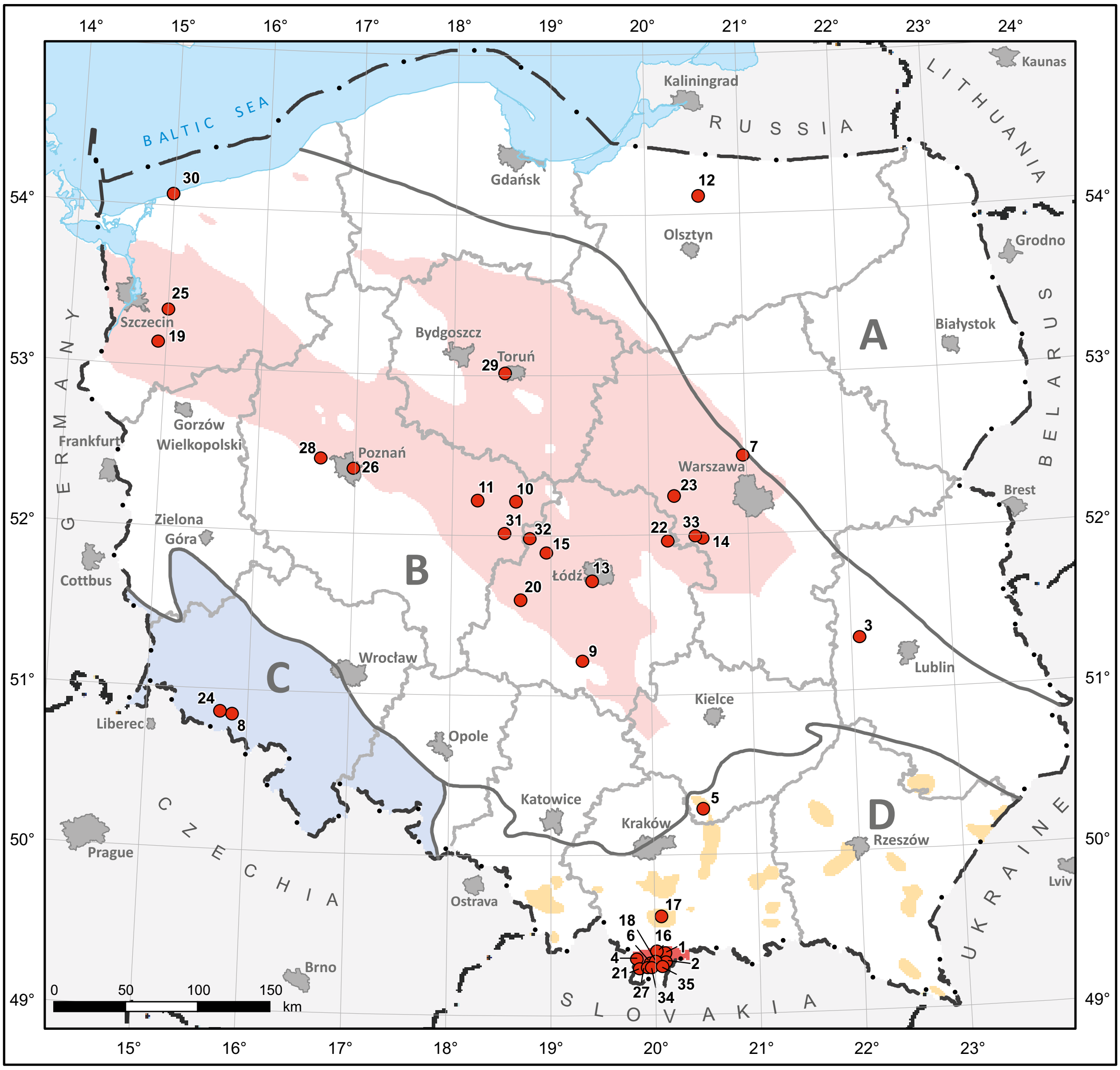
In the area of Polish Lowland, thermal waters from the Lower Cretaceous and Lower Jurrasic formations are the most prospective for use. They occur in widespread hydrogeological basins (covered structures). In the Carpathians thermal water occurs in the Cretaceous, Paleogene and Neogene formations, and in the Triassic deposits of the Podhale Trough, which is characterized by a small area and strong tectonic influence (i.e. Bańska, Biały Dunajec, Białka Tatrzańska, Bukowina Tatrzańska). In the Carpathians Forehead, thermal waters occur in the Cambrian, Devonian, Carboniferous, Jurassic, Cretaceous and Miocene formations. In the Sudetes the most prospective formation is the Carboniferous aquifer in the vicinity of Jelenia Góra-Cieplice. Thermal water also occurs in Lądek-Zdrój, Duszniki-Zdrój and Grabin in the vicinity of Niemodlin. Thermal water is used for



Explanations for the numerical symbols on the map:

1 – Busko II; 2 – Busko-Północ; 3 – Ciechocinek; 4 – Cieplice; 5 – Czarna Górna źr. nr 5; 6 – Czerniawa-Zdrój; 7 – Czeszewo IG-1; 8 – Dar Natury; 9 – Dębowiec III; 10 – Długopole-Zdrój; 11 – Dobrowoda I; 12 – Dobrów IGH-1; 13 – Duszniki-Zdrój; 14 – Dziwnówek Józef; 15 – Frombork IGH-1; 16 – Galicjanka III - Pole 1, Pole 2; 17 – Głębokie Kinga; 18 – Goczałkowice-Zdrój I; 19 – Gołdap; 20 – Gorzanów; 21 – Grabin 5/1 (Odra); 22 – Horyniec; 23 – Inowrocław I; 24 – Inowrocław II; 25 – Iwonicz; 26 – Jamno IG-3; 27 – Jaworze IG-1, IG-2; 28 – Jedlina-Zdrój; 29 – Kamień Pomorski; 30 – Kołobrzeg II; 31 – Komańcza źr. nr 1; 32 – Konstancin; 33 – Konstantynów; 34 – Kotowice; 35 – Krościenko n. Dunajcem; 36 – Krynica Morska IG-1; 37 – Krynica-Zdrój I; 38 – Krzeszowice I; 39 – Las Winiarski; 40 – Las Winiarski; 41 – Latoszyn-Zdrój; 42 – Lądek-Zdrój; 43 – Leluchów L-4; 44 – Lesko (źródła nr 1, 4); 45 – Lipa Zdrój-1; 46 – Lusina; 47 – Łagiewniki; 48 – Łagów Lubuski IG-1; 49 – Marusza; 50 – Mateczny I; 51 – Międzywodzie (Kamień Pomorski IG-1); 52 – Muszyna; 53 – Muszyna INEX; 54 – Muszyna Zdrój; 55 – Muszynianka III; 56 – Nałęczów II; 57 – Nieborów źródła; 58 – Opatkowice; 59 – Piła IG-1; 60 – Piwniczna-Łomnica; 61 – Polanica-Zdrój; 62 – Polańczyk; 63 – Połczyn; 64 – Przerzeczyn; 65 – Rabe 1; 66 – Rabka-Zdrój; 67 – Rajcza-Plebania SWR-1; 68 – Rymanów; 69 – Rzeszów (S-1, S-2); 70 – Solec-Zdrój; 71 – Sopot; 72 – Sosnówka źródła; 73 – Sól S-1 Miriam; 74 – Sól-Tężnia; 75 – Stara Łomnica; 76 – Stare Bogaczowice źródła; 77 – Stare Rochowice; 78 – Stary Wielisław; 79 – Swoszowice; 80 – Szczawa; 81 – Szczawiczne II; 82 – Szczawina; 83 – Szczawnica I; 84 – Szczawnik-Cechini; 85 – Szczawno-Zdrój; 86 – Ślesin IGH-1; 87 – Środa IG-2; 88 – Świeradów-Zdrój; 89 – Świnoujście I; 90 – Trzebnica IG-1; 91 – Tylicz I; 92 – Ustka; 93 – Ustroń; 94 – Wapienne; 95 – Wapienne INEX; 96 – Wełnin; 97 – Wieliczka W-VII-16; 98 – Wieniec; 99 – Wierchomla Wielka; 100 – Wierchomla Wielka źródła; 101 – Wilga IG-1; 102 – Wołczyn VII A; 103 – Wysowa; 104 – Zabłocie-Korona; 105 – Złockie Z-7; 106 – Zubrzyk; 107 – Żegiestów INEX; 108 – Żegiestów-Cechini; 109 – Żegiestów-Zdrój; 110 – Żegiestów-Zdrój Główny; 111 – Łapczyca

Figure 12.1. Occurrence of curative waters in Poland



thermal water deposits

hydrogeological regions of curative waters (after Dowgiałło, Paczyński, 2002):
A – Precambrian Platform Province
B – Paleozoic Platform Province
C – Sudetes Province
D – Carpathians Province

state boundaries

province boundaries

Perspective areas of occurrence of thermal waters:

Polish Lowlands – Lower Cretaceous and Lower Jurassic reservoirs (after Górecki, ed., 2006)

Outer Carpathians – Paleogene and Mesozoic reservoirs and Carpathian Foredeep – Neogene, Mesozoic and Paleozoic reservoirs (after Górecki, ed., 2011, 2012, 2013)

Podhale Trough – Paleogene and Mesozoic reservoir (after Paczyński, Płochniewski, 1996)

Sudetes and Fore-Sudetic Block (after Dowgiałło, Paczyński, 2002)

Explanations for the numerical symbols on the map:
1 – Białka; 2 – Bukowina; 3 – Celejów; 4 – Chochołowskie Termy; 5 – Cudzynowice; 6 – Furmanowa PIG-1; 7 – Jachranka; 8 – Karpniki; 9 – Kleszczów GT-1; 10 – Koło; 11 – Konin GT-1; 12 – Lidzbark Warmiński GT-1; 13 – Łódź (EC-2 otw. nr 3); 14 – Mszczonów; 15 – Poddębice; 16 – Podhale 2; 17 – Poręba Wielka; 18 – Poronin; 19 – Pyrzyce; 20 – Sieradz GT-1; 21 – Siwa Woda IG-1; 22 – Skierniewice GT-1, GT-2; 23 – Podhale 2; 17 – Poręba Wielka; 18 – Poronin; 19 – Pyrzyce; 20 – Sieradz GT-1; 21 – Siwa Woda IG-1; 22 – Skierniewice GT-1, GT-2; 23 – Sochaczew GT-1; 24 – Staniszów; 25 – Stargard Szczeciński I; 26 – Swarzędz IGH-1; 27 – Szymoszkowa; 28 – Tarnowo Podgórne GT-1; 29 – Toruń; 30 – Trzęsacz GT-1; 31 – Turek GT-1; 32 – Uniejów I; 33 – Wręcza GT-1; 34 – Zakopane; 35 – Zazadnia IG-1

Figure 12.2. Occurrence of thermal water in Poland

heating, relaxation and fish farming, the food industry, and for municipal purposes (to drink, for heating sidewalks and sports fields).

In 2020 reserves of groundwater classified as minerals amounted to 7,222.52 m^3/h in 146 deposits. The reserves of thermal water were estimated at 5,291.30 m^3/h, curative water – 1,927.52 m^3/h and brine 3.70 m^3/h. Over the last five years the resources of groundwaters considered as minerals increased by about 1,393.14 m^3/h, and in the last decade increased by about 2,997.21 m^3/h. Since 2015, the number of deposits increased from 132 to 146, whereas the resources of thermal water increased by about 1,126.5 m^3/h (2,745.6 m^3/h since 2010) and curative water increased by about 266.64 m^3/h (251.61 since 2010). For the brines no change was observed. Currently 81 deposits are being exploited in Poland. In 2015 the number of active deposits was determined to be 78.

The amount of brine, curative and thermal waters intake in 2015 was calculated at 12,971,535.70 m^3/year. In comparison to 2015 it has increased by about 782,464.51 m^3.

The prospective resources of curative water that can be used, calculated as the difference between the value of disposable resources and reserves, amount to 38,455.37 m^3/h and increased over seventy-fold compared to 2009 (Sokołowski, Skrzypczyk, 2020). In the case of brine static resources in the Łapczyca deposit should be considered as prospective resources in the amount of 32,139.61 m^3/h (Felter, 2020; Sokołowski, Skrzypczyk, 2021). In the case of thermal water only their energy resources are specified. The prospective exploitation resources of thermal water energy are approximately $9.0–9.1 \cdot 10^{18}$ J per year (Socha, Skrzypczyk, 2020).

13. Noble metals and jewellery stones

M. Hodbod

13.1. Chrysoprase

Chrysoprase is a rare variety of silica made from a mixture of cryptocrystalline chalcedony, quartz and opal. An advantage of one of these components allows several varieties of chrysoprase to be distinguished: opal chrysoprase (prazopal), chalcedony-opal chrysoprase, chalcedony chrysoprase, and quartz chrysoprase. Chrysoprase is translucent, sometimes diaphanous on the corners, glassy or half glassy, sometimes greasy burnish. Its characteristic green color is the result of an admixture of nickel compound e.g. schuchardite, pimelite, garnierite. Depending on the admixture content and proportions, the color can have variable shades – from light green to emerald/dark green. The most valuable varieties are characterized by a high degree of transparency together with an intense dark apple green or dark emerald green color. Chrysoprase occurs within weathering zones of ultrabasic rocks. Nevertheless, the deposits of any practical significance are mainly connected with the strong silification zones within serpentinites. They can also arise as the result of silica precipitation from hydrothermal solutions e.g. near granitoid intrusions (Niśkiewicz, 1982; Sachanbiński, 1985).

Chrysoprase is attractive and highly appreciated precious stone used in for collecting, decoration and jewelry. It had already been appreciated in ancient Egypt, Rome and Greece. It was particularly popular from the 17th to the first half of 19th century. It was mainly used for the production of gallantry, souvenirs, amulets and jewelry. Sometimes it was used as facing, decorative or incrustative stone.

Chrysoprase occurs very seldom in the bigger agglomerations of an economic significance. One of the unique deposits is located in Poland, and therefore Poland has been for years, one of the world leaders in chrysoprase exploitation. Since the end of the 19th century chrysoprase was being exploited as the accompanying raw material with nickel ore, in Szklary near Ząbkowice Śląskie, in the Sudetic Foredeep (Lower Silesia). Initially, underground exploitation was used, while in the 20th century exploration moved mainly to opencast mining. In the final period of the mine's operation (1970s and 1980s) there were a maximum of 2 t of chrysoprase being exploited annually. The chrysoprase deposit in the Szklary Massif occurs with serpentinites in the form of veins, lenses and nests. The occurrence of opal, serpentine, talc and magnesite is also characteristic. The biggest specimens reached even a dozen or so kilograms (Sachanbiński, 1985). In the central area of Szklary (the Szklana Góra hill) there were 5 prospective areas of chrysoprase occurrence, within yellow-brown and red-brown earthy mantle rock with a preserved structure of primary rock, with increased nickel content (Niśkiewicz, 1982). Small chrysoprase occurrences are also known from serpentinites in the vicinities of Grochowa, Braszowice, Koźmice, Wiry and Wirki near Sobótka (Żaba, 2006). At present, chrysoprase is obtained only by collectors (Mizerski *et al.*, 2020).

13.2. Nephrite

Nephrite is a metamorphic rock composed of closely fit cryptocrystalline fibers of the silicates mineral group consisting mainly of the calcium-iron-magnesium amphibolite from the actinolite series. Nephrite can contain some admixtures of other minerals such as e.g. chromite, diopside, and magnetite. It is non-translucent, with the greasy burnish. It is green in color – variable in shade: from light green to dark green. Sometimes it forms patchy or striped, veined, marbly varieties – resulted from iron oxide admixtures. Grey-white, milky-white, creamy-beige, yellowish, grey-brown, black, sometimes red color specimens are also found. The high cohesion and conciseness of the internal structure make nephrite exceptionally resistant to mechanical damage – the breakdown of nephrite require the pressure exceeding 7 t/cm^2. Nephrite formed as a result of metasomatic processes with the dirt from acidic or alkali igneous rocks moved into dolomites, dolomitic marbles or serpentinites – under significant pressures and increased temperature (Heflik, 1974, 2010).

Nephrite was already known in the ancient times, especially in China, where it was used for the production of tools, amulets, decoration, sculpture, medicines, and even weapon. At present, nephrite is used for decorative and utility products, artistic souvenir items, sculpture and jewelry.

Nephrite occurrences are relatively rare in nature, and the largest can be found in for e.g. Australia, Brazil, China, Canada.

Poland occupies second place in Europe regarding nephrite resources. Nephrite occurrences were found in the Lower Silesia, in the vicinity of Jordanów, Szreblów and Tąpadło Pass, in the vicinity of Złoty Stok and in the Izery Mts. The best explored deposits occur in Jordanów Śląski within serpentinite forming the hill range surrounding the Ślęża Massif from south and east. In this area nephrite occurs in the form of nests and veins which formed blocks up to 40 cm in thickness and 2.5 m in length extracted. At present, the quarry is abandoned. In 2007 there was a nephrite occurrence discovered in the serpentinite quarry in Nasławice, located in the pass of the Nasławice Hills, within the Gogołów-Jordanów Massif. It confirms the occurrence of a rich, several kilometer-long nephrite zone between Jordanów and Nasławice (Łobos *et al.*, 2008). Nephrite resources have not been documented so far. There is no exploitation of this stone carried out (Mizerski *et al.*, 2020).

13.3. Other

Agate is one of the oldest known decorative stones in the world. They were exploited as early as 3,000 BC in the areas of present-day Saudi Arabia or Egypt. Agates are compact silica agglomerations, in which chalcedony dominates. Subordinate compounds are several variations of opal and micro- and macro-crystalline quartz. They are diaphanous or translucent with conchoidal fracture of wax burnish. They can be spherical, ellipsoidal, lensed, veined, but also more complicated and deformed. The border with the surrounding rock is clearly visible. A characteristic feature of agate is a multi-colored banded chalcedony. Particular bands can be grey, white, grey-blue, brown, black, rarely yellow, orange, red, red-orange, blue, green, which is the result of the admixture of various minerals such as e.g. chlorites, hematite, goethite, seladonite. Spaces between bands are filled by microcrystalline quartz. In some agates mega-quartz druses can also be spotted, which are formed in the final phase of the silica crystallization process. Bands are usually aligned monocentric or polycentric, rarely parallel, but they can also occur in pseudo-infiltrative forms or other colorful ornaments. Depending on the formed pattern, the characteristics of colors distribution or the type of band structure, there are several dozen agate types distinguished, e.g. dendritic, mossy, lacy, fortress, landscaped, smudge, ribbon, star-shaped, amoebic, circular, brecciaous. The rare agate types are onyx, sardonyx and – characterized by a schillerization effect – fiery and iridescence agate.

Agate usually occurs in the sub-volcanic igneous rocks, whose igneous alloys were highly saturated by steam and hot gases and then underwent cooling near the earth surface. They formed in the post-gaseous voids, growing from the walls to the center. They can rarely be spotted in pyroclastic rocks, sedimentary rocks, and inside fossils (Żaba, 2006; Manecki, 2015).

Due to the variety of colors and patterns formed in agates, these stones are highly demanded for collecting purposes. They are used for the production of e.g. decorative gallantry, artistic utility objects, jewelry, and for the production of abrasives, polishing materials, bearings, tools for the textile industry and laboratory equipment.

The occurrence of agates in Poland is connected with the outcrops of volcanic igneous rocks (melaphyres, rhyolites, trachybasalts) mainly in the Lower Silesia in the Kaczawa Mts. and Kaczawa Foreland (Nowy Kościół, Płóczki Dolne, Dynowice, Różana, Wielisław Złotoryjski, Lubiechowa, Sokołowiec, Prześdiedza, Wleń), in the vicinities of Kamienna Góra, Wałbrzych, Mieroszów (Sokołowsko), Głuszyca (Świerki), Nowa Ruda (Tłumaczów) and Kłodzko (Suszyn, Mrowieniec, Czerwieńczyce). Agates are also known from the area of Krzeszowice, near Cracow (Alwernia, Rudno, Regulice).

The most prospective – for agates exploitation – are the Rotliegend deposits in the vicinity of Nowy Kościół (Mizerski *et al.*, 2020).

Rock crystal (pure quartz, traditionally also called clear quartz) is a colorless, diaphanous variety of quartz, characterized by a high hardness and chemical weathering resistance. Most often, it forms columnar, hexagonal crystals with sharp endings. Sometimes in the crystals there may be inclusions of other minerals occurring e.g. rutile, goethite, pyrite, hematite, tourmaline, chlorite or fluidal or gaseous inclusions causing a white color (milk quartz). Rock crystals are mostly found in igneous rocks and hydrothermal sediments, but can also occur in the metamorphic and sedimentary rocks. Especially beautiful developments are found in pegmatites druses and hydrothermal veins (Żaba, 2006).

Rock crystal was highly valued as a gemstone until the 18th century. Then its importance decreased as a result of a growing production of synthetic stones. At present, it is used for silica glass production, in the crystal growth of synthetic quartz, sometimes in the optical and electrotechnical industries. It is also used for the production of jewelry, decorative gallantry, souvenirs, utility or artistic items. At the same time, it is still a highly-valued stone by collectors.

In Poland, the most beautiful crystals occur in the quartzitic schist quarry in Jegłowa, near Strzelin, in the Sudety Upland. The biggest crystal found there was 20 cm long and 5 cm wide and weighed in at 260 grams. There impressive druses can also be found. Rock crystals also occur in many other places in the Lower Silesia: in dolomite in Sławniowice near Głuchołazy (Eastern Sudety Mts.), in the vein quartz mine Stanisław on the Izery Humps (Izery Mts.), in Taczalin near Legnica, Strużyno near Strzelin, in the vicinity of Strzegom (Jaroszów, Graniczna, Żółkiewka, Grabina, Zimnik), in the vicinity of Jelenia Góra (Łomnica, Karpniki), Szklarska Poręba, Sobótka, Bolesławiec, Lądek Zdrój, Kłodzko and many other towns. They are also spotted in abandoned melaphyre quarries in the vicinity of Cracow (Poręba, Rudno near Tenczynek, Niedźwiedzia Góra, Krzeszowice), within Tatry granite and Carpathian flysch sandstone (e.g. vicinities of Jabłonka and Szczawy) (Żaba, 2006).

Jasper is a siliceous rock of sedimentary, volcanogenic or metamorphic origin, containing mainly of chalcedony and quartz. Jasper is hard, compact and non-translucent. Its color varies in a wide range: red-brown, red, cherry, yellow, orange or brown, rarely green, pink, blue, purple, white or black. Such variety of colors is caused by admixtures of other minerals, mainly iron and manganese compounds, but also chlorites, epidote, zoisite. Sometimes admixtures of carbonates, mica, clayey substances, garnets, pyroxene can also occur. Additionally, the following patterns can be formed: striped, ribbon, smudge, spotted, dappled, mottled, stringy, marbly, brecciaous, spherical, motley. Jasper can occur in the form of veins, lenses, encrustations, beds, concretions, whereas in alluvial and glacial sediments in the form of pebbles.

Jasper is a popular jewelry-decorative stone, known throughout history – e.g. as the Nile stone from ancient Egypt. It is used in the production of jewelry, and as a decorative stone for the production of artistic, utility and souvenir items. Sometimes it is used as a facing stone, for the production of table tops, mosaic, but also for encrustation (Heflik, Pawlikowski, 1977; Żaba, 2006).

Jasper is widely spread throughout nature, sometimes forming large aggregations that possess characteristics of a deposit. The most famous and valued deposit in the world is located in Russia (Ural Mts.), where monolithic blocks of jasper weighting a couple of tons each are being exploited.

In Poland, jasper occurs mainly in Świerki near Nowa Ruda in the Lower Silesia, in the form of beds within the Permian melaphyres. Their thickness is up to 1.8 m. Jasper is also known from quarries in Czadrowo, on the Ostoja mountain in Głuszyca Górna, Suszyn and Niwa, Prześdziedza near Wleń, Płuczki and Pławna and in the vicinity of Marciszów, Nagórnik, Stare Bogaczowice and Dobromierz. Except for the Sudetes area, jasper can be also found in diabases of Niedźwiedzia Góra near Krzeszowice in the vicinity of Cracow, in sedimentary rocks in Lanckorona near Wadowice, and in dolomites in the Bobrowniki-Blachówka mine in Upper Silesia (Gaweł, 1953; Heflik, Pawlikowski, 1977; Żaba, 2006).

CHAPTER III

Resources and reserves evidence with data for future economy demand

14. Mineral resources databases

J. Fabiańczyk, I. Gryszkiewicz, A. Malon, M. Szuflicki, M. Tymiński

14.1. Database on Polish mineral raw material deposits – MIDAS

Registration, storage and processing of data on resources and output of mineral raw materials in Poland are some of the main tasks of the Polish Geological Institute – National Research Institute. PGI-NRI is charged with oversight of the Polish Geological Survey according to Art. 163 of the GML. One of the tasks performed by the PSG is to run a national balance of mineral resources (Art. 162 of the GML). To complete this task it is necessary to possess an appropriate database. Such a database – the **System of management and protection of mineral resources in Poland (MIDAS)** – is maintained by the Economic Geology Department at PGI-NRI. The MIDAS system has been systematically updated since 1988 and contains information on all mineral raw material deposits, their resources base and on their output and development possibilities.

There are two sources of information for the MIDAS system:

- geological documentation collected by the PGI-NRI National Geological Archive (prepared according to the "Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987) and "Regulation by the Minister of the Environment on a geological-investment documentation of a hydrocarbons field" (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 968) – covering basic information on deposits such as location, structure, hydrogeological conditions, raw material types and parameters, and deposit resources;
- statistical forms prepared by concession holders and sent annually to PIG-NRI (by the 15th of March – according to Art. 101 of the GML) – containing information on the annual output and changes in the resources of a deposit.

All data mentioned above are regularly entered into the database. The service can be found on the MIDAS website http://www.midas.pgi.gov.pl. It is available only in Polish and provides access to 3 groups of information: deposits; mining areas and mining countries as well as related concessions; mineral resources management. Anyone interested in the mineral resources of Poland should select the "viewing data" button (which forwards to http://geoportal.pgi.gov.pl/midas-web) and then "Złoża kopalin" on the top left side of the webpage and will be redirected to the website where specific deposit data can be found. Upon selection of a single deposit (by its name or number), detailed information can be gained and analyzed. Such information contains: deposit location (name of town or village, voivodeship); documentation(s) number of a deposit collected in the NGA; deposit concession holder(s); type of area above a deposit; underground water levels (depth, quality); raw material data – thickness and depth, shape, qualitative parameters, resources and output; exploitation system; raw material processing (ore dressing); land reclamation planned in the future. A deposit can also be presented on a map and a special report (called in Polish "karta złoża" – deposit sheet) with all necessary information on a deposit can be generated and downloaded in .pdf format.

Spatial data presented on the MIDAS website relating to: mineral deposits, mining areas and mining countries are – among other data collected by the PGI-NRI – available as shapefiles on the website https://dm.pgi.gov.pl.

The MIDAS system is a very important tool for fulfilling the tasks placed on PGI-NRI. Its main uses are as follows:

- data source for preparing the "The balance of mineral resources deposits in Poland" (only in Polish) publication – prepared annually,
- basis for the "Mineral Resources of Poland" publication – prepared approximately every 5 year,
- basis for the Mineral Resources of Poland website – prepared annually,
- important source of information for local government and government administration.

"The balance of mineral resources deposits in Poland" is a task of the Polish Geological Survey and must be issued by the 30th of June (according to the GML) by order of the Ministry of the Environment. It is financed by the National Fund for Environmental Protection and Water Management. The publication has been issued since 1953 and its latest edition (as of the end of 2020 –

Szuflicki *et al.*, eds., 2021) contains data on 14,429 Polish mineral raw material deposits. "The balance…" presents mineral raw materials within 4 groups: energy, metallic, chemical and rock raw materials. These groups are selected on a basis of a raw material's utility as a mineral commodity. Each raw material is described in a separate chapter. Each chapter provides information on a raw material's occurrence in Poland, types of deposits, raw material quality and its utility. There are also usually 2 types of tables presented in a chapter – one, with national data (includes types of resources, resources categories and state of deposit development), and another with regional or administrative information (where deposits with their resources and output are listed). Until the 2011 edition (as of the end of 2010), also provided was data on potable- and industrial-grade groundwater resources, waste from exploitation and processing of raw materials, and on export and import. Presently, "The balance…" covers only the information on brines, curative and thermal water, whereas data on export and import are presented on the website Mineral Resources of Poland.

The **"Mineral Resources of Poland"** is published written in English, prepared by the Economic Geology Department at PGI-NRI. The current publication is the 6th edition of the "Mineral Resources of Poland". Similar to the publication in Polish ("The balance…"), it divides raw materials into 4 main groups and each raw material is described in a separate chapter. The publication (apart from the 2017 publication – Szamałek *et al.*, eds., 2017) contains an analysis over a 5-year period in a table presenting the size of raw material resources, state of their identification and management (on a national scale) and – for the most important raw materials – a graph showing their resource base and output over a representative period of time. There is also a set of maps presenting mineral raw material deposits occurring in Poland. This publication is aimed at supporting the central government administration i.a. in terms the security of domestic resources and providing geological knowledge to potential foreign investors that are interested in building their business in Poland in the area of mineral resource deposit development. It applies not only to the stages of prospecting and exploration mineral deposits, but also to the exploitation of mineral raw materials.

The **Mineral Resources of Poland website** is available under the link: http://surowce.pgi.gov.pl. It was established in 2011, based on the MIDAS system and "The balance…", and is annually updated by the Economic Geology Department at PGI-NRI. It is presented both in Polish and in English, and provides the most important information on resources of mineral raw material deposits in Poland, the state of their development and their output. The portal also contains:

- a set of maps presenting mineral raw material deposits occurring in Poland;
- a set of geological concession maps;
- information on the import and export of mineral raw materials;
- archival editions of "The balance…" (in Polish) – from 1955 to the most recent one (in .pdf format);
- archival editions of the "Mineral Resources of Poland" (in .pdf format);
- definitions of resources and their categories, as required by Polish law (according to the regulations by the Minister of the Environment: Journal of Laws of 2012, Item 511 and Journal of Laws of 2015, Items: 968 and 987);
- 2 editions – 2012 and 2013 – of the Minerals Yearbook of Poland (and also its Polish version – "Bilans Gospodarki Surowcami Mineralnymi Polski i Świata") reviewing mineral commodity production and use in Poland.

The distribution maps available on the website (updated annually) include: hard coal deposits in the USCB; hard coal deposits in the LCB; copper ores deposits; zinc and lead ores deposits; dimension and crushed stone deposits in South-Western Poland; dimension and crushed stone deposits in South-Eastern Poland; oil and gas fields; hard coal, brown coal and peat deposits; metal ores and chemical raw materials deposits; rock raw materials deposits (excluding dimension and crushed stone); ceramic and refractory raw materials deposits (excluding building ceramics raw materials); building ceramics raw materials deposits; clastic rock raw materials deposits. All of these maps can be downloaded in .jpg format.

Concession maps are prepared monthly and a set of maps consists of: a concession map for hydrocarbon exploration and production, and non-reservoir storage of substances and waste in the subsurface; a map of drilling work being currently conducted for the purpose of natural gas and crude oil prospecting and exploration (on a base of map of hydrocarbon concessions divided according to exploratory targets); concession map for the prospecting, exploration and production of rock, chemical and metal deposits; concession map for hard coal and CBM prospecting, exploration and production in the USCB; concession map for hard coal and CBM prospecting, exploration and production in the LCB; concession map for hard coal and CBM prospecting, exploration and production in the LSCB; concession map for prospecting, exploration and production of lignite deposits; map of brines, curative and thermal water production licences, and geological work projects for prospecting and identifying waters considered as a mineral resources.

Information on trade turnover in the imports and exports of mineral raw materials from and to Poland is available via the MIDAS system, based on data collected by the Polish Tax and Customs Service based on data provided on customs declaration forms and INTRASTAT statistical declarations. Data does not include the information from the entities which do not have a legal obligation to report their activity in the INTRASTAT system, or which have not fulfilled the obligation within the required time limit. The customs declaration forms apply to the trade of goods carried out between European Union Member States and countries which are not EU Member States. Such declarations are the basis for the EU statistical system EKSTRASTAT. The INTRASTAT system, however, is a statistical system containing the trade statistics between EU Member States and has been obligatory on the European Single Market since the 1st of January, 1993. The INTRASTAT declarations have to be completed when the value of commodities exceeds a certain threshold – the threshold values are annually defined by the President of Statistics Poland and published in the statistical survey program implemented as a regulation by the Prime Minister. Import and export data contains the valuation and size of a particular raw material, and on the nation-wide scale, the turnover balance and the directions of trade. Detailed data from the previous year is presented including multiannual information in the form of tables or graphs. Until 2009 said information was collected in the PRICESMIN database, but since then it has been relocated to one of the modules of the modernized MIDAS system, named the "Economy of raw materials" available on the website under the link: http://geoportal.pgi.gov.pl/midas-web/pages/index.jsf?conversationContext=1 (in Polish).

The Mineral Resources of Poland website provides all the important information on mineral raw material deposits (in Polish, as well as in English) and allows users to download the content. It is regularly visited – in the 4th quarter of 2021 the number of visits (sessions) amounted to 8,679 and the number of views was equal 22,418. New visitors to the website accounted for 96.7%, whereas returning visitors accounted for 3.3%. Most users visited the Polish-language version of the website (about 85.4%), however there was a significant number of guests interested in the English version (about 14.6%).

14.2. Spatial data

Collecting, processing and providing access to spatial data pertaining to documented raw materials deposits is one of the priority tasks of the Polish Geological Survey. The spatial data related to the boundaries of deposits, mining areas and mining countries are provided: by prepared mapping compositions (e.g. mapping data from the MIDAS system), by WMS and WFS web services, and also in the form of vectors in the shapefile format (.shp).

The MIDAS system website presenting i.a.: spatial data on documented raw materials deposits boundaries, mining areas and mining countries, is available under the link: http://www.midas.pgi.gov.pl. A map interface provides all users with quick and easy access to geological information. The MIDAS system is a referencing database, where spatial data is collected and then used in other applications and services or exported to shapefiles. The current view of data collected in the database is secured only by the online MIDAS service, other described sources providing spatial data are updated on a 24 hour basis.

Spatial data is also presented using the InfoGeoSkarb system available at: http://geoportal.pgi.gov.pl/igs. The application contains coordinates of contour points of documented deposits boundaries, mining areas and mining countries in the Polish coordinate systems, including the WGS84.

MIDAS system spatial layers, with data spanning the area of the entire country, are also available in the form of the shapefiles – a format supported by most GIS spatial information systems. Detailed information on such files is provided by means of the MIDAS system website, under the "Spatial data" section (http://geoportal.pgi.gov.pl/portal/page/portal/midas/dane_przestrzenne).

Individuals interested in spatial information can also use the WMS and WFS mapping services published by PGI-

NRI. Thus, a user can review spatial data in raster form on any geoportal or program supporting web services. Detailed information on WMS and WFS services is available on the MIDAS system website in the "Spatial data" section (http://geoportal.pgi.gov.pl/portal/page/portal/midas/dane_przestrzenne).

Public access to spatial data is also offered by the PGI-NRI geoportals: the mobile application GeoLOG available under the link: https://geolog.pgi.gov.pl and the mapping portal Geology available at: https://geologia.pgi.gov.pl.

The above-mentioned solutions enable a quick search of information in a selected area, the generation of reports and, most importantly, analyses, and access to easy interpretations of the presented spatial information. The spatial data on documented raw materials deposits is, on one hand, the basis for decision-making pertaining to the mineral policy in Poland (providing support to geological administration) and on the other hand, provide any user data on a selected area (providing support for investments, as well as environmental, economic and other types of decisions).

14.3. Mineral Groundwater Data Bank

A specific collection of data is the Mineral Groundwater Data Bank. It is a database in which information is collected on hydrogeological objects – sources, exploitation, research and observation boreholes located throughout the country, collecting healing and thermal waters and brine (all classified as minerals), as well as mineralized and specific waters that due to their physical and chemical properties may be classified as minerals in the future. The database is available online under the link: http://spd.pgi.gov.pl/PSHv8.

In the Mineral Groundwater Data Bank, attribute, descriptive and numerical information is collected from hydrogeological documentation, documents owned by the intake users, and various archival studies and publications. Both geological data and geological/hydrogeological information are stored in this database.

The basic contents of information stored in the database include: location of the hydrogeological object, a lithostratigraphic profile, construction data of the intake, measured and calculated hydrogeological data, laboratory results of the physicochemical properties of water and of the gases dissolved in it, as well as their isotopic composition, and information from hydrogeological documentation and documents on the exploitation of waters issued by appropriate geological administration entities. The database also stores descriptive and spatial information on mining areas, resource areas and spa protection zones. The location of objects and spatial data can be visualized using the map module.

Currently, the database contains information on over 2,000 hydrogeological objects from all over the country. Database resources are being constantly supplemented and updated.

15. Mineral raw materials balance

15.1. Output of mineral raw materials

A. Malon, M. Tymiński

This chapter presents tendencies in the raw materials output in Poland during the 1989–2020 period. The total number of deposits documented in Poland changed significantly over the analyzed period (Fig. 15.1.1). In 1989 and 1990, this number did not exceed 5,000, but then has been systematically increasing – to 7,000 in 1998, 8,000 in 2002, 10,000 in 2008 and more than 14,500 in 2020. In the period being covered by this publication (2016–2020), the number of deposits increased by 931 (that is by 6.85%). The number of documented deposits in 2020 was more than threefold larger than in 1989. The amount of exploited deposits grew slightly until 1998 – however not exceeding 2,600. The following years brought quite faster growth regarding the number of deposits – over 3,000 in 2004, more than 4,000 in 2010 and exceeding 5,100 in 2014. The highest number of exploited deposits during this analyzed period was recorded in 2017 – it amounted to 5,113. In the following 3 years (2018–2020) the number fell by 199 (3.89%) and returned to the amount recorded in 2012. In 1989, exploited deposits accounted for 47.3% of total documented deposits and this contribution declined until 1998 (to 36%). By 2010, the rate did not change significantly. In the next several years, it slightly grew to 37% in 2015, but was still much lower than in 1990s. The 2016–2020 period brought quite a significant ratio decrease – to 33.9% and it was the lowest point over the whole presented period (32 years). Rock raw materials deposits (especially these of sand and gravel) account for more than 90% of all documented deposits in Poland, so tendencies within this group determine the entire domestic situation. Until 1997, their contribution did not exceed 90%, but in the following years it has been systematically increasing – and reached the highest point of 94.5% in 2020. The analyzed period was characterized by significant increase in the number of documented deposits, while the number of exploited deposits (for all raw materials and rock group) was changing much slower rate. This was mainly because not all new deposits have been the subject of exploitation immediately after documentation. The significant increase in the number of exploited deposits can be seen especially until 2014 (by about 100 deposits annually), whereas in 2015–2020 it fell by 196 (3.84%). The growing number of documented deposits did not always influence increases in resources. It might have been due to a size of new documented deposits – much smaller than the already documented ones. The best example is the sand and gravel raw material for which the largest deposits (with resources between 10 and 500 Mt) account for only 3.4% of total number, but which resources account for 56.22% of the domestic resources base.

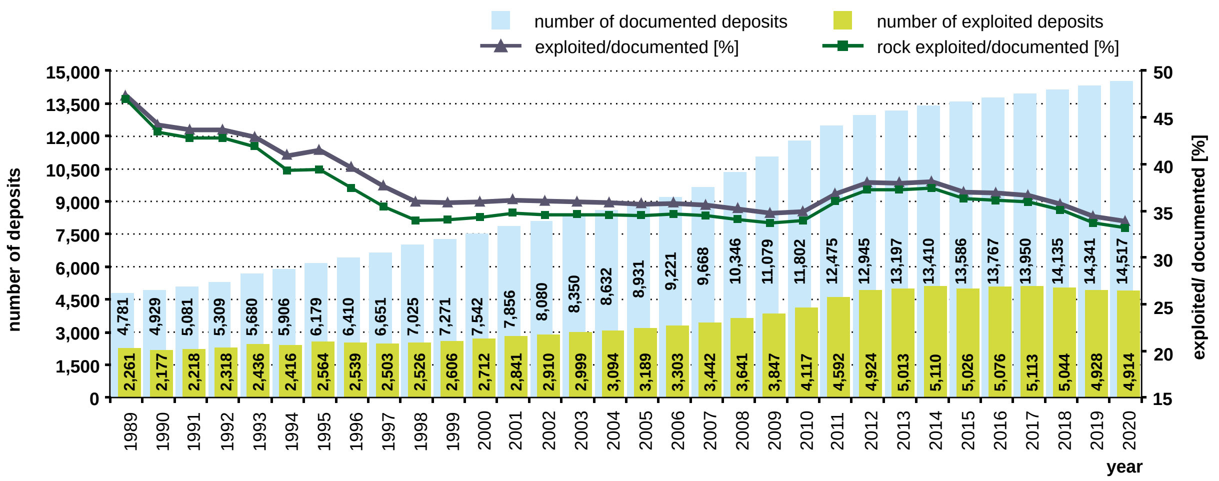


Figure 15.1.1. Number of documented and exploited raw material deposits in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

As for specific raw material groups, the most important – regarding the number of documented deposits and number of exploited deposits – is the rock raw materials group (especially sand and gravel deposits; Fig. 15.1.2). In 2020, it accounted for 94.50% of all deposits documented in Poland and for 92.57% of deposits currently under exploitation. These rates have not changed significantly over the analyzed period, but have been systematically increasing – they amounted to 87.01% and 86.29% in 1989, 91.16% and 86.98% in 2000, 93.84% and 91.33% in 2010, 94.33% and 92.46% in 2015. The number of exploited rock raw material deposits increased by 2,598 – from 1,951 in 1989, to 4,549 in 2020 (2.3 fold). There were annual decreases recorded in: 1990, 1994 and 2015; a 2-year decrease in the 1996–1997 period and a 3-year decrease over the 2018–2020 period. In 2020, deposits of energy raw materials are the second largest group with their number of documented deposits accounting for 4.90% of domestic deposits, and with a number of exploited deposits accounting for 7.00% of their total number. Exploited deposits of this group fluctuated slightly during the entire analyzed period, within the range of 282–369 deposits, with an increase in 1989–1997 and then mainly with decreases recorded in the remaining years. It was mostly due to hard coal mine closures, but in the meantime documenting new fields of natural gas and crude oil during the entire period. The 2 other groups of raw materials (chemical and metallic) are of lesser importance, with a number of exploited deposits being 12 and 9 in 2020, respectively. Exploited chemical raw material deposits fell in number from 15 to 10 in 1994–1999, as a result of sulfur and barite/fluorite mine closures due to economic conditions. In the following years they remained without minor changes – a slight increase from 10 to 11 deposits in 2013, and from 11 to 12 deposits in 2019, resulting from the start of exploitation of rock salt and sulfur deposits, respectively. The number of exploited metallic raw material deposits decreased from 13 to 9 in 1990 (iron, zinc and lead ore mine closures and the end of exploitation of copper ores in the North Sudetic Basin), and finally remaining at 8–9.

Output of the metallic and chemical raw materials groups in 1989–2020 has changed significantly (Fig. 15.1.3). It remained within the range of 24–34 Mt per year and 3–9 Mt per year, respectively.

Natural gas and CBM output fell in 1990 and then was systematically increasing until 2009 and exceeded 6 bnm³. Over the next 11 years, it decreased to 5.25 bnm³. Coalbed methane output constitutes only about 5–6% of both types of gas exploitation. Output of other energy raw materials (excluding natural gas and CBM) declined over the analyzed period – from almost 248 Mt in 1989 to only 96 Mt in 2020 (by 61.29%). Such changes resulted mainly from limitation of hard coal exploitation. It started at 176 Mt in 1989, then amounted to 102 Mt in 2000, 69 Mt in 2010, 65 Mt in 2015 and only 48.16 Mt in 2020 (the lowest in history). This was due to the Polish coal mines being the subject to restructuring since the start of the transformation of the national economy at the end of the 1980s – to adjust the mining sector to requirements of the free-market economy. A negative tendency in en-

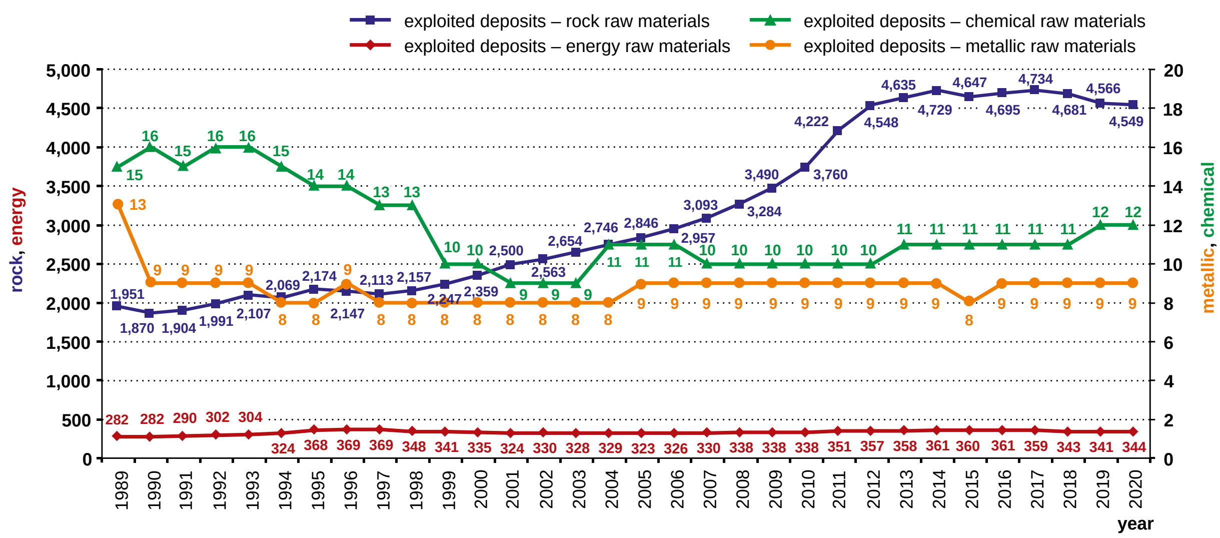


Figure 15.1.2. Number of exploited deposits within four raw materials groups in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

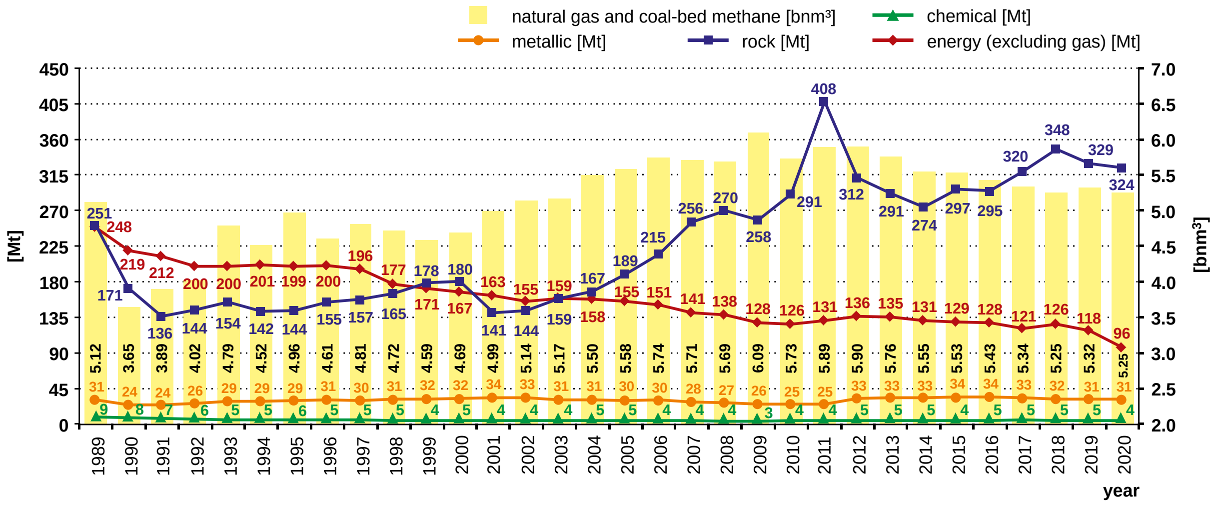


Figure 15.1.3. Output of mineral raw materials groups, natural gas and coal-bed methane in 1989–2020

According to: "The balance of mineral resources deposits and groundwater resources in Poland" (in Polish; Przeniosło, ed., 1990–2005; Przeniosło, Malon, eds., 2006; Gientka, *et al.*, eds., 2007, 2008; Wołkowicz *et al.*, eds., 2009–2010; Szuflicki *et al.*, eds., 2011), "The balance of mineral resources deposits in Poland" (in Polish; Szuflicki *et al.*, eds., 2012–2021)

ergy raw materials output reversed in 2011–2012 when not only hard coal exploitation slightly increased, but also there was a significant increase in lignite output. Crude oil production is of less importance (about 1 Mt annually).

The rock raw material group has a biggest share of the raw material output in Poland. There are 3 mineral raw materials determining the size of output – sand and gravel, dimension and crushed stone and limestone and marl for the cement and lime industries. They accounted for 55.57%, 23.60% and 14.64% of total group output in 2020, respectively. In 1989, these shares were 37.01%, 12.58% and 19.86%, in 2000 49.00%, 13.36% and 19.96%, whereas in 2010 they were 56.16%, 21.73% and 13.75%, respectively. Output of rocks fell in 1990–1991 to 136 Mt and then increased over the next 9 years to 180 Mt. In 2001, a 1-year decrease was recorded, mainly due to decreases in all of the 3 main raw materials – by 15 Mt in sand and gravel, 6 Mt in limestone and marl and 2 Mt in dimension and crushed stone. In 2002–2011, exploitation grew by 267 Mt (nearly threefold). It coincided with political-economic events, such as the Polish association with the EU, the accession of Poland to the EU, and the global economic crisis. These factors caused increasing demand, especially in the building and road construction sectors. A significant increase in 2011 (by 117 Mt in comparison to 2010) was strictly related to the growing demand for raw materials in a road-building sector, due to preparations being made for the 2012 UEFA European Championship organized in Poland and Ukraine. Sand and gravel production increased by 85.2 Mt in 2011, whereas dimension and crushed stone, and limestone and marl increased by 21.4 Mt and 9.0 Mt, respectively. The next 3 years (2012–2014) brought a decrease in output due to a halt investments, whereas an increasing tendency returned in 2015 and 2017–2018, when new instalments for road investments commenced. In 2019, the output of sand and gravel decreased by 14.2 Mt as the result of an end on road investments (on motorways S6, S17, A2 and S5) and the economic situation in a building construction sector. Another decrease in 2020 (by 2.6 Mt) was recorded due to the economic situation disturbances (mainly as a result of the COVID-19 pandemic). These were the main reasons for a total decrease of the rock raw material group in Poland – its exploitation amounted to 329 Mt in 2019 and 324 Mt in 2020.

15.2. Exports and imports of mineral raw materials

M. Tymiński

Information on trade turnover in exports and imports of mineral raw materials in Poland is prepared annually on a basis of data collected by the Polish Tax and Customs Service. The presented information is actual data coming from custom declarations and INTRASTAT declarations. The data do not include the upward adjustments from entities which were not required to report in the INTRASTAT system, and which have not fulfilled the obligation within the required time limit. The custom declarations apply in the trade in goods carried out by the European Union Member States with third countries that are not EU Member States. Such declarations are a basis for the UE statistical system EKSTRASTAT. The INTRASTAT system, however, is the statistical system containing trade information between EU Member States and is obligatory for the European Single Market since the 1st of January, 1993. The INTRASTAT declarations have to be filled when a commodity's value exceeds a certain threshold – such thresholds are defined annually by the President of Statistics Poland and published in the statistical survey program introduced in a form of regulation by the Prime Minister. In 2020, the basic threshold for commodity import was PLN 4 M, whereas for export it was PLN 2 M. According to the information from the Polish Tax and Customs Service, underestimation of the trade turnover data not exceeding the mentioned above limits in 2020, amounted to 4.9% of imports and 1.9% of exports.

A list of presented commodities is updated annually according to the Polish Tax and Customs Service tabulations. These tabulations are based on the integrated Tariff of the European Union – TARIC. The legal base for TARIC is the "Council Regulation (EEC) No 2658/87 of 23 July 1987 on the tariff and statistical nomenclature and on the Common Customs Tariff" (Official Journal L 256, 07/09/1987). The regulation was amended by "Commission Regulation (EU) No 1006/2011 of 27 September 2011 amending Annex I to Council Regulation (EEC) No 2658/87" (Official Journal L 282, 28/10/2011). The TARIC is based on the Combined Nomenclature (CN) which is set up to meet the requirements both of the Common Custom Tariff (CCT) and of the EU's external trade statistics. The CN is also used in the intra-EU trade statistics. The CN was established by the "Council Regulation (EEC) No 2658/87" on the tariff and statistical nomenclature and on the Common Customs Tariff. Every year, Annex I to the basic CN Regulation (No 2658/87) is updated and published as a stand-alone Regulation in the EU's Official Journal (L series). The CN contains about 10,000 items and works on an 8-digit code system – it is the further development (with the special EU-specific subdivisions) of the World Customs Organization's Harmonized System Nomenclature (HS). On a 6-digit level the CN is analogous to the HS. The HS was established by the "International Convention on the Harmonized Commodity Description and Coding System" prepared under auspices of the World Customs Organization in Brussels of the 14th of June, 1983 (Official Journal No 11, pos. 62, 1997).

TARIC is the multilingual database integrating all measures relating to the EU customs tariff, commercial and agricultural legislation. The TARIC is updated and maintained daily in almost every one of the EU languages. The TARIC data are transmitted daily via an electronic network to the Member States, which guarantee immediate and correct information for the national administrations of the Member States, who use this data mainly to feed their national systems for customs clearance, with a goal of maximizing automatic customs clearance. The TARIC is not legally binding, nevertheless its codes have to be used during customs clearances and in statistics according to Art. 5 of "Council Regulation (EEC) No 2658/87" amended by "Council Regulation (EC) No 254/2000 of 31 January 2000 amending Regulation (EEC) No 2658/87" (Official Journal L 28, 3/02/2000).

In Poland, the TARIC database is maintained by the Customs Department of the Ministry of Finance as a part of the Integrated Customs Tariff Information System – ISZTAR 3. It provides detailed information concerning commodity turnover to the Customs Administration and to all interested parties concerned by that issue. Both, the EU data coming from the TARIC system, and the Polish data (VAT and excise taxes), as well as some national non-tariff measures not integrated in the TARIC database, are presented in the browser. Similarly to the TARIC, the ISZTAR is not legally binding; nevertheless its codes have to be used during the custom clearance and in statistics.

Data on the mineral raw materials turnover do not cover natural gas. The data on natural gas export and import are not available since 2006, due to the confidential nature of such information – according to the "Regulation (EC) No 638/2004 of the European Parliament and of the Council of 31 March 2004 on Community statistics relating to the trading of goods between Member States and repealing Council Regulation (EEC) No 3330/91" (Official Journal L 102, 7/4/2004). Natural gas export from Poland is minor (in 2019 amounted to 0.67 bnm^3 – about 670 Mt) and lack of data does not significantly affect the total balance of raw materials trade. The lack of data on the natural gas import to Poland significantly brings down the total amount and value of raw materials imported to Poland. Data officially presented by the Central Statistical Office of Poland cover only the amount of natural gas imported by Poland, but without publishing the directions of import markets. Therefore, such data are not included in this study; nevertheless, it should be noted that in the analyzed period natural gas import increased from 9–10 bnm³ in 2009–2010 to about 14.95 bnm³ in 2018 and 16.75 bnm³ in 2019 (information covering 2020 will be issued later). Therefore, it is worth mentioning that the balance of mineral raw materials trade is higher than the balance taking into account the figures on natural gas.

Trade turnover in the raw materials sector in Poland increased significantly after the Polish accession to the EU. It was seen especially in the statistics covering 2004 and following years both in the value and the amount of import and export. The last 10 years (2011–2020) also brought changes in the trade balance (Fig. 15.2.1).

Export quantities increased from about 30 Mt in 2011 to 37 Mt in 2015 and then there was a declining tendency observed until 2020 – the amount of exports dropped to 29.5 Mt. Import decreased significantly in 2012 and 2013 and then grew in 2014–2018 to a level of 83.2 Mt. The last 2 years were characterized by a declining tendency – in 2020 the quantity of imports amounted to 71.3 Mt. Export and import values – due to changing raw materials prices – were not the subject of the same changes. The export value was characterized by a declining tendency until 2016 (to about PLN 47,920 M), then it grew to PLN 58,400 M and fell within the last 2 years to PLN 52,930 M. The value of imports decreased significantly in 2013–2016 – to about PLN 78,320 M, then increased to almost PLN 120,000 M and last 2 years brought a decrease to about PLN 83,800 M.

Variations in the balance of imports-exports by value and quantity, for the last 10 years are shown in Figure 15.2.2. The balance value increased substantially in 2012–2015 – to PLN −29.32 bn. This tendency changed in 2017 and 2018 when the balance changed to PLN −59.50 bn. The last 2 years brought a significant improvement of the balance – in 2020 it reached PLN −30.87 bn. The quantity balance grew significantly in 2012–2013 – to −23.31 Mt and then was systematically dropping to −50.61 Mt in 2018. Similarly to the balance value, it improved in the 2019–2020 period to −41.78 Mt. Taking into account the amount of gas imported, reported by the Central Statistical Office of Poland (about 16.75 bnm³ in 2019), in 2020 the balance would change to about −58.53 Mt.

Summary statistics for minerals and mineral commodities in Poland in 2020 are presented within 4 groups: fuels, metals, chemicals and rocks. The total amount and value of imports-exports of raw materials, as well as of particular groups of raw materials are presented in Table 15.2.1.

The total value of the raw materials exports decreased by PLN 3,391 M (EUR 1,150 M) that is by 6.02% in comparison with the previous year and amounted to PLN 52,933 M (EUR 11,956 M) in 2020. The import value amounted to PLN 83,806 M (EUR 18,987 M) and decreased by PLN 24,252 M (EUR 6,156 M) that is by 22.44%. The exports-imports trade balance remained

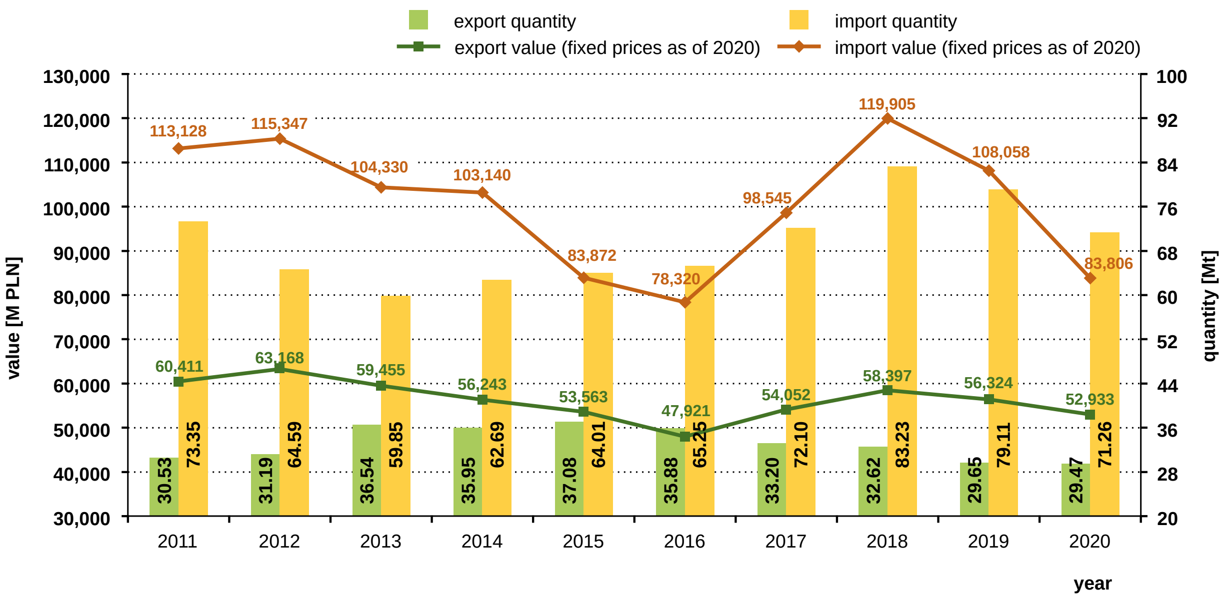


Figure 15.2.1. Mineral raw materials exports and imports in terms of value and quantity in 2011–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data negative and was more profitable then in 2019 – by PLN 20,861 M (EUR 5,006 M) and amounted to PLN 30,873 M (EUR 7,031 M) in 2020 (excluding natural gas). It was the 2nd consecutive year with the negative balance had decreased.

Total quantity of the raw materials imports fell by 9.93% (7,852 kt) in 2020 and amounted to 71,256 kt, while the export quantity decreased by 0.59% (174 kt) and amounted to 29,472 kt. The balance remained negative and amounted to –41.78 Mt – excluding natural gas.

Figures 15.2.3 and 15.2.4 show a structure of raw materials exports and imports in Poland in 2016 and 2020, i.e. total values and shares of various types of raw materials in international trade. Generally speaking, main subjects of trade remained the same with crude oil, petroleum products, hard coal and copper among them. Prices of these commodities decide on the final balance value.

The most important, regarding the value of the raw materials exports in 2020, were raw materials and products such as: copper (16.54% of the total export value), hard

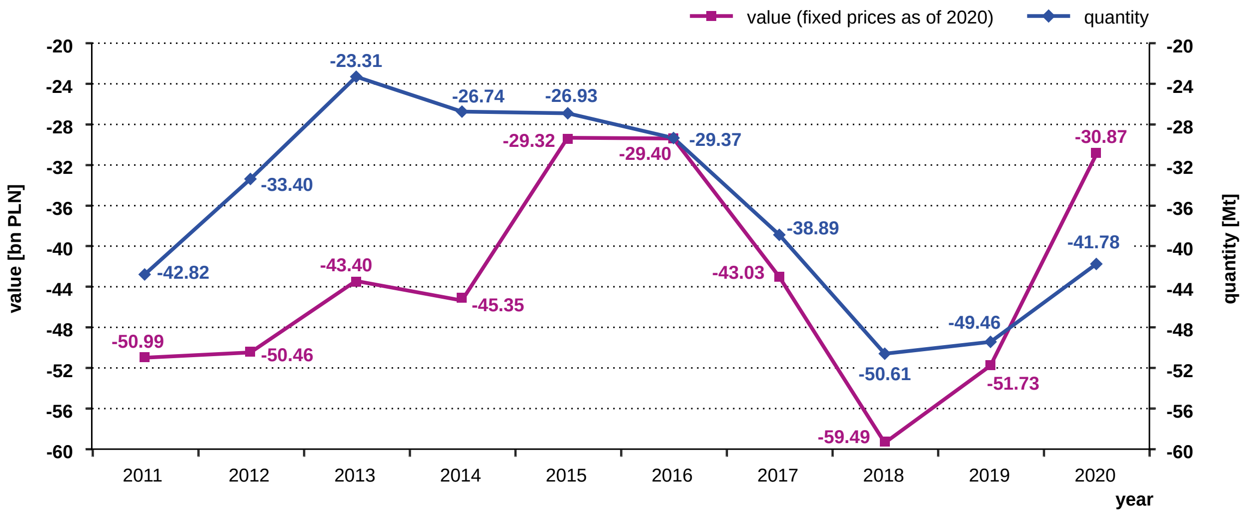


Figure 15.2.2. Balance of mineral raw materials imports and exports in terms of value and quantity in 2011–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

Table 15.2.1. Imports and exports of mineral raw materials in 2020 (value in PLN and EUR)

Group of mineral raw materials	Import Export					Balance		
	Quantity [kt]	[%]	Value [k PLN]	Value [k EUR]	[%]	Quantity [kt]	Value [k PLN]	Value [k EUR]
TOTAL	**71,256*** **29,472***	**100.0** **100.0**	**83,805,850*** **52,932,794***	**18,987,145*** **11,955,692***	**100.0** **100.0**	**–41,783***	**–30,873,056***	**–7,031,453***
Fuels	46,677* 16,361*	65.5* 55.5*	50,014,264* 16,234,930*	11,347,734* 3,678,816*	59.8* 30.8*	–30,317*	–33,779,333*	–7,668,918*
Metals	9,315 3,863	13.1 13.1	23,822,012 28,605,998	5,385,216 6,447,193	28.4 53.9	–5,452	+4,783,986	+1,061,977
Chemicals	6,174 4,359	8.7 14.8	6,525,211 4,806,804	1,477,220 1,088,229	7.8 9.1	–1,815	–1,718,407	–388,991
Rocks	9,089 4,889	12.8 16.6	3,444,364 3,285,062	776,975 741,453	4.1 6.2			
						–4,200	–159,302	–35,521

* excluding natural gas

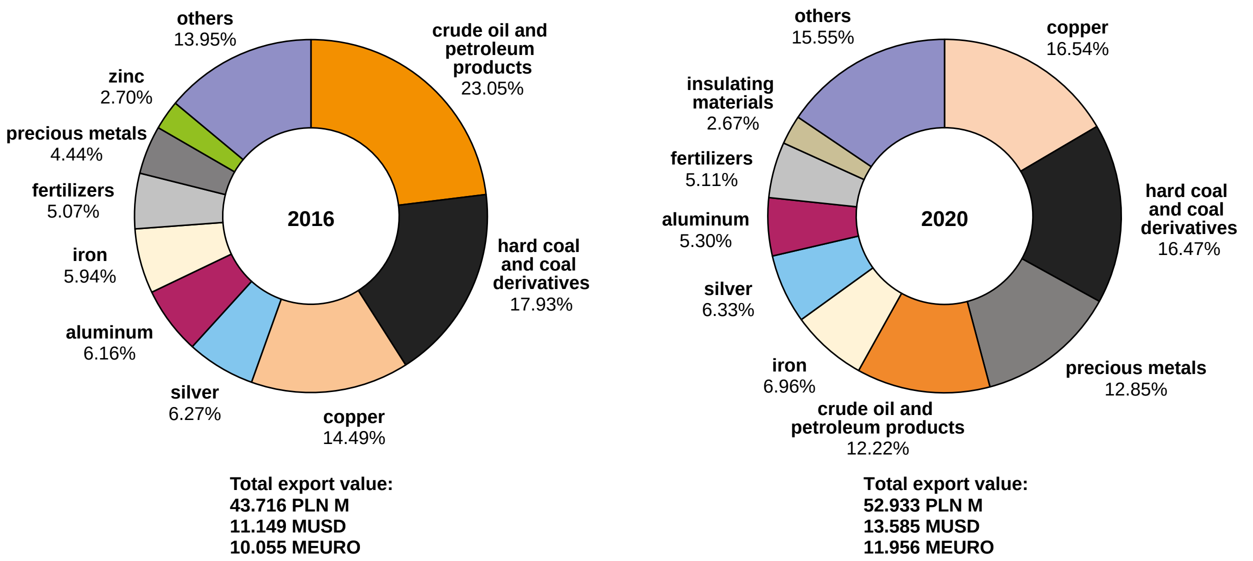


Figure 15.2.3. The structure of mineral raw materials exports in 2016 and 2020

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

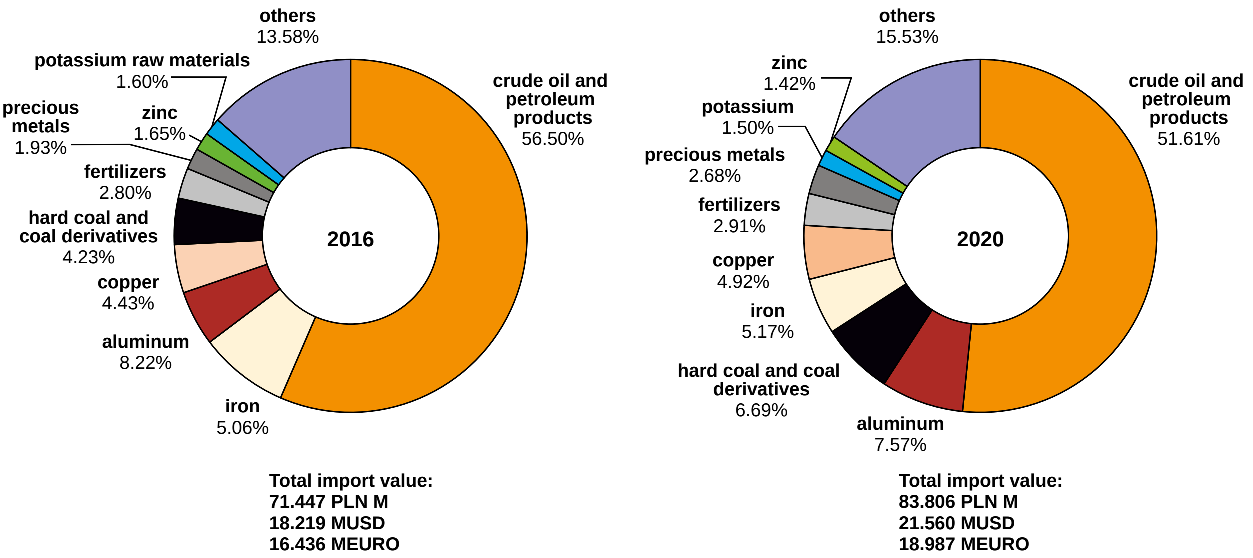


Figure 15.2.4. The structure of mineral raw materials imports in 2016 and 2020

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

coal and coal derivatives (16.47%), precious metals (12.85%), crude oil and petroleum products (12.22%), iron and ferroalloys (6.96%), silver (6.33%), aluminum (5.30%), nitrogen and multi-component fertilizers (5.11%) and insulating raw materials (2.67%).

The highest values of imports, causing a negative trade balance in 2020, related mainly to such raw materials as: crude oil and petroleum products (51.61% of the total import value), aluminum (7.57%), hard coal and coal derivatives (6.69%), iron and ferroalloys (5.17%), copper (4.92%), nitrogen and multi-component fertilizers (2.91%), precious metals (2.68%), potassium (1.50%) and zinc (1.42%).

Percentage contributions of the particular groups of raw materials to the value of exports and imports in the 2016–2020 period are presented in Figures 15.2.5 and 15.2.6. Fuels (energy raw materials) are still the most important group, especially in Polish imports (due to crude oil and petroleum products), but they have lost their dominant position regarding export.

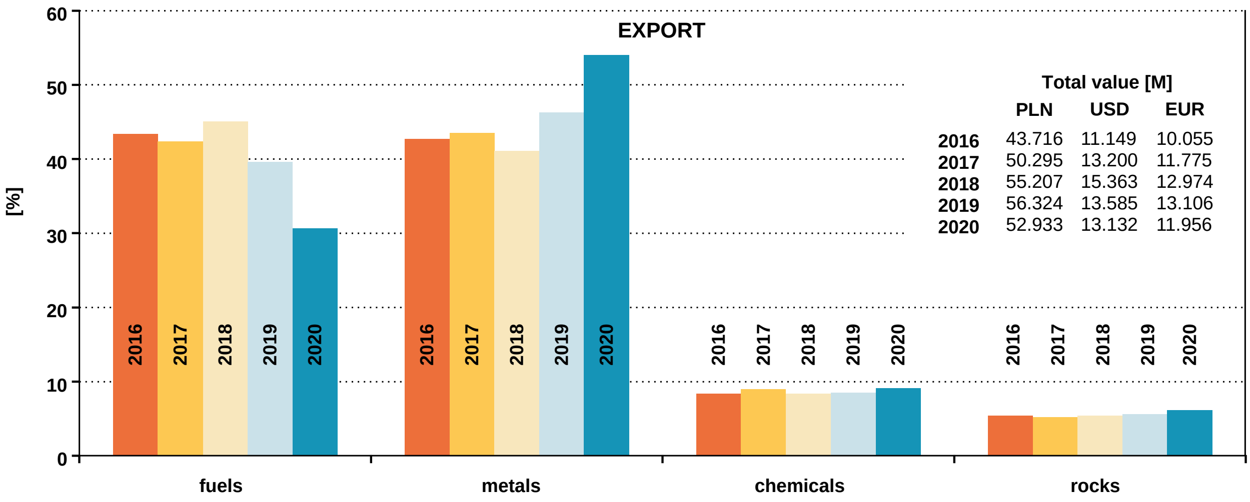


Figure 15.2.5. Contribution of raw materials groups to the value of exports in 2016–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

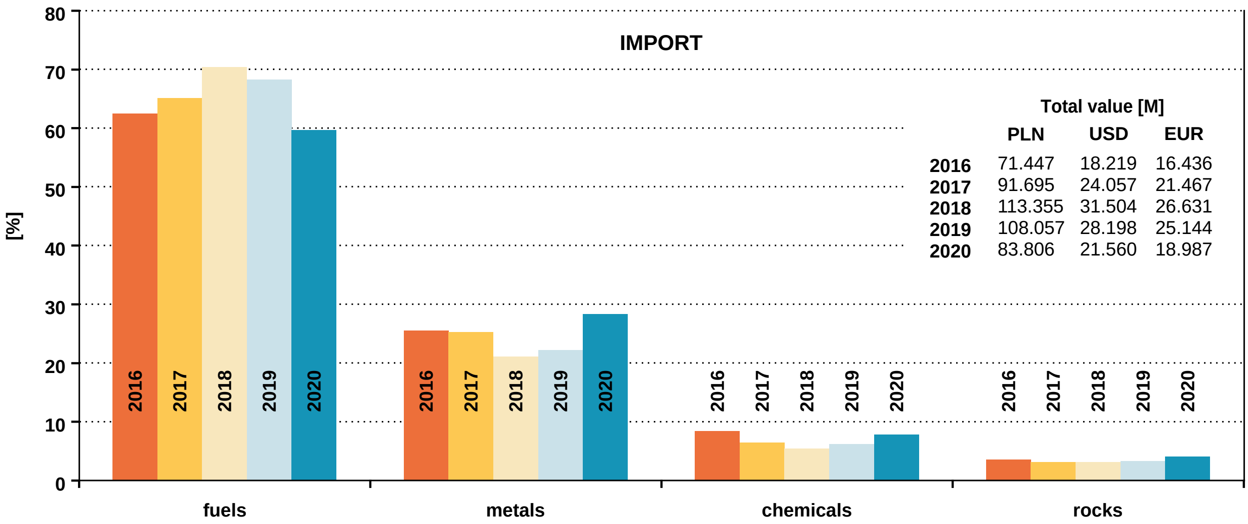


Figure 15.2.6. Contribution of raw materials groups to the value of imports in 2016–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

Contributions to the export value have been oscillating significantly for 2 mineral groups (fuels and metals) during the last 5 years, with chemical and rock raw material export pretty stable in the analyzed period. The highest increases of value with respect to the previous year were noted in 2019 and 2020 for metals – by 5.2% and 7.7%, respectively. For the last 2 years metals have been the most important group partaking in the value of Polish exports, mainly thanks to copper and precious metals exports. This raw material group has replaced fuels, which were dominant in the Polish raw materials export for years. The biggest drops in export were recorded in 2019 and 2020 for fuels (by 5.5% and 8.9%, respectively), due to a declining export value of hard coal (and coal derivatives) and petroleum. The 2020 level of contribution for this raw material group was the lowest in Polish history.

The proportion of the contribution of import to the value of import was changing for 3 raw materials groups – fuels, metals and chemicals. After a significant increase in the 2017–2018 period – to 70.4%, the contribution of fuels fell to only 59.7% in 2020 (the lowest level in the analyzed period), whereas it increased for metals in 2019 and 2020 by 1.1% and 6.2%, respectively (to 28.4%). The contribution of chemical raw materials fell in 2017 and 2018, by 2.9% and 1.1%, respectively, and then increased by 0.8% and 1.6% over the next 2 years. Rock raw materials remained stable at 3.1–4.1% in the analyzed period.

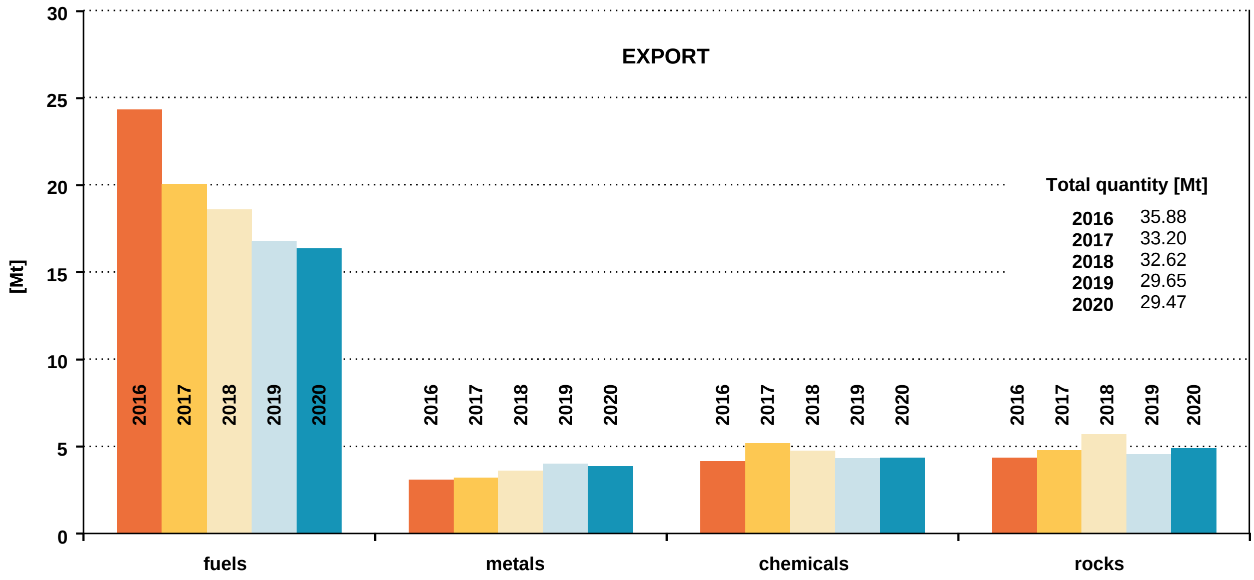


Figure 15.2.7. Magnitude of mineral raw materials exports in 2016–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

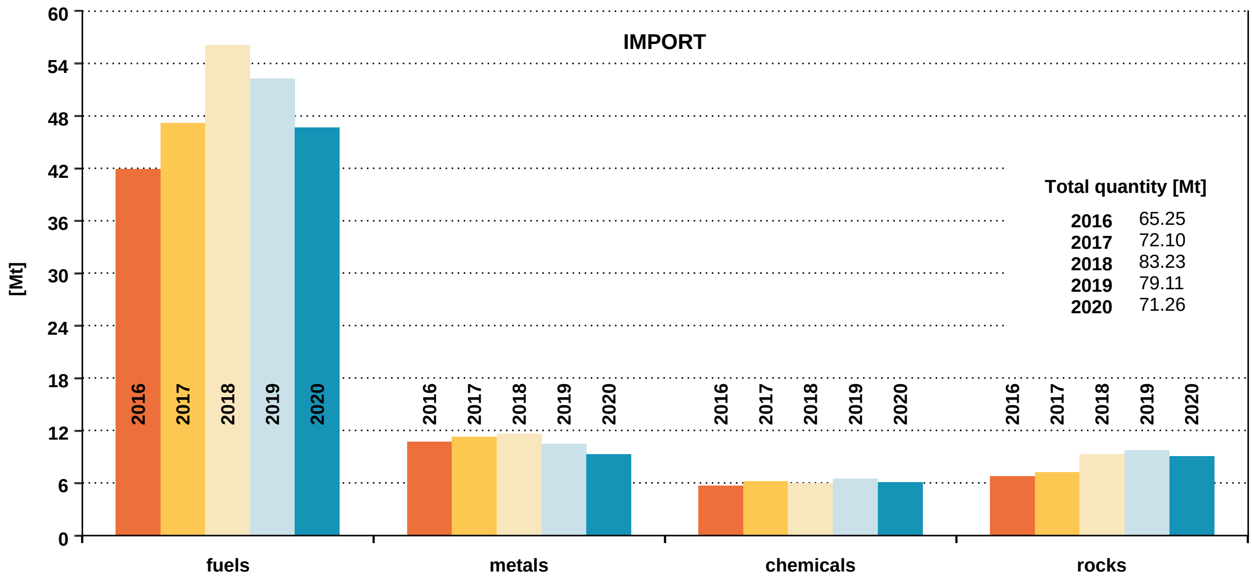


Figure 15.2.8. Magnitude of mineral raw materials imports in 2016–2020 (excluding natural gas)

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

The graphs presented on Figure 15.2.7 and 15.2.8 show the amount of exports and imports of particular raw material groups. It can be seen that the export of fuels has been decreasing significantly over the whole period – from 24.32 Mt in 2016 to 16.36 Mt in 2020 (that is by 32.73%), with metals increasing from 3.08 Mt to 3.86 Mt (25.32%) and 2 other groups slightly fluctuating, but remaining quite stable: 4.15–5.8 Mt for chemical raw materials and 4.33–5.70 Mt for rock raw materials (Fig. 15.2.7).

Regarding import quantity, only chemical raw material group remained stable at about 5.80–6.52 Mt. Metals fell in the analyzed period from 10.74 Mt to 9.31 Mt (that is by 13.31%), whereas the import of rocks raw material increased from 6.82 Mt to 9.09 Mt (by 33.28%). There were substantial changes recorded for fuels – their imports amount increased from 41.93 Mt to 56.14 Mt in the 2016–2018 period (by 33.89%), and then a declining tendency occurred – the import quantity fell to 46.68 Mt in 2020 (by 16.85% in comparison with 2018; Fig. 15.2.8).

Tables given below show a comparison between import/export values (Table 15.2.2) and quantities (Table 15.2.3) in 2019–2020.

Total import value in 2020 decreased by PLN 24,252 M (EUR 6,156 M) that is by 22.44% and export value fell by PLN 3,391 M (EUR 1,150 M) that is by 6.02% in comparison with 2019. The import value amounted to PLN 83,806 M (EUR 18,987 M), whereas the export value to PLN 52,933 M (EUR 11,956 M). The import value fell for all of raw materials groups: fuels – by 32.20% (PLN 23,752 M; EUR 5,817M); chemicals – by 3.30% (PLN 223 M; EUR 274 M); rock raw materials – by 2.93% (PLN 104 M; EUR 10 M); metals – by 0.72% (PLN 173 M; EUR 198 M). The export value increased for 3 raw materials groups: – by 9.79% (PLN 2,550 M; EUR 386 M) for metals, by 4.56% (PLN 105 M; EUR 10 M) for rock raw materials and by 0.07% (PLN 3 M; a drop in terms of EUR by EUR 30 M) for chemicals, whereas there was a significant decrease noted for fuels – by 27.27% (PLN 6,088 M; EUR 1,517 M).

Table 15.2.2. Comparison between export/import values in 2019–2020 (value in PLN and EUR)

import
export

Group of mineral raw materials	2019			2020			Comparison		
	Value [M PLN]	Value [M EUR]	[%]	Value [MPLN]	Value [M EUR]	[%]	Absolute value 2020–2019 [M PLN]	[% of PLN value] 2019=100	Absolute value 2020–2019 [M EUR]
TOTAL	**108,057.50*** **56,323.89***	**25,143.62*** **13,105.93***	**100.0** **100.0**	**83,805.85*** **52,932.79***	**18,987.15*** **11,955.69***	**100.0** **100.0**	**–24,251.65*** **–3,391.10***	**77.56*** **93.98***	**–6,156.47*** **–1,150.24***
Fuels	73,766.40* 22,322.72*	17,164.33* 5,196.07*	68.3* 39.6*	50,014.26* 16,234.93*	11,347.73* 3,678.82*	59.7* 30.7*	–23,752.14* –6,087.79*	67.80* 72.73*	–5,816.60* –1,517.25*
Metals	23,994.60 26,056.07	5,582.72 6,061.00	22.2 46.2	23,822.01 28,606.00	5,385.22 6,447.19	28.4 54.0	–172.59 2,549.93	99.28 109.79	–197.50 386.19
Chemicals	6,748.18 4,803.44	1,750.82 1,117.76	6.2 8.5	6,525.21 4,806.80	1,477.22 1,088.23	7.8 9.1	–222.97 3.36	96.70 100.07	–273.60 –29.53
Rocks	3,548.31 3,141.66	825.75 731.09	3.3 5.6	3,444.36 3,825.06	776.97 741.45	4.1 6.2	–103.95 143.40	97.07 104.56	–48.78 10.36

* excluding natural gas

Table 15.2.3. Comparison between export/import quantities in 2019–2020 [Mt]

import
export

Group of mineral raw materials	2019		2020		Comparison	
	Quantity	[%]	Quantity	[%]	Absolute value 2020–2019	[%] 2019=100
TOTAL	**79.11*** **29.65***	**100.0** **100.0**	**71.26*** **29.47***	**100.0** **100.0**	**–7.85*** **–0.18***	**90.08*** **99.39***
Fuels	52.29* 16.78*	66.1* 56.6*	46.68* 16.36*	65.5* 55.5*	–5.61* –0.42*	89.27* 97.50*
Metals	10.50 4.00	13.3 13.5	9.31 3.86	13.1 13.1	–1.19 –0.14	88.67 96.50
Chemicals	6.52 4.32	8.2 14.6	6.17 4.36	8.7 14.8	–0.35 0.04	94.63 100.93
Rocks	9.80 4.55	12.4 15.3	9.09 4.89	12.8 16.6	–0.71 0.34	92.76 107.47

* excluding natural gas

In 2020, the total import amount decreased by 9.92% (7.85 Mt) and export by 0.61% (0.18 Mt) in comparison with 2019. The quantity of imports decreased for all of raw materials groups: for metals by 11.33% (1.19 Mt); for fuels by 10.73% (5.61 Mt), for rock raw materials by 7.24% (0.71 Mt), whereas for chemicals by 5.37% (0.35 Mt). The export quantity increased for rock raw materials – by 7.47% (0.34 Mt) and for chemicals – by 0.93% (0.04 Mt). The 2 remaining groups recorded decreases – the amount of exports decreased by 3.50% (0.14 Mt) for metals and by 2.50% (0.42 Mt) for fuels.

Figures 15.2.9 and 15.2.10 show main market directions of raw materials exports and imports in Poland, in 2016 and 2020.

Regarding both exports and imports, the main trade partners have not changed significantly. In 2020, similarly to the previous years, the highest value was attained by raw materials exports to Germany. It amounted to PLN 13,516,794 k (EUR 3,047,173 k), which constituted 25.54% of total Polish raw materials exports value. Other important countries with a significant contribution to

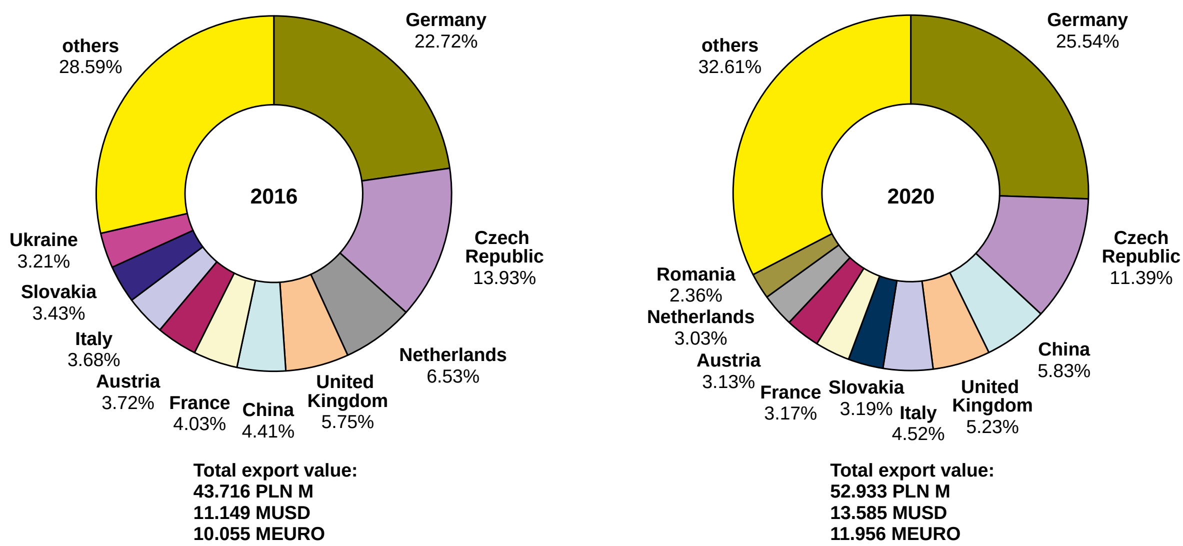


Figure 15.2.9. Main directions of raw materials export in 2016 and 2020

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data

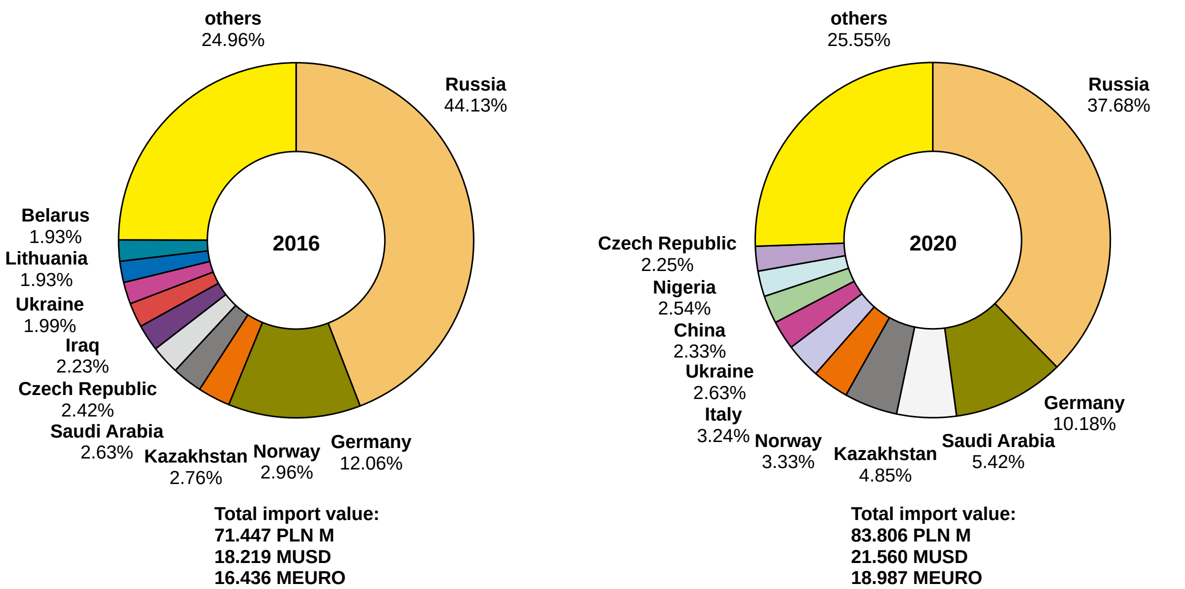


Figure 15.2.10. Main directions of raw materials import in 2016 and 2020

According to: the System of management and protection of mineral resources in Poland – MIDAS; source: the Polish Tax and Customs Service data the total Polish raw material exports value were the Czech Republic (11.39%; PLN 6,026,667 k, EUR 1,363,658 k) and China (5.83%; PLN 3,088,529 k, EUR 692,717 k; Fig. 15.2.9). Total export value to these 3 countries amounted to PLN 22,631,991 k (EUR 5,103,549 k; 42.76% of total export value).

In 2020, the major part of the mineral raw material imports came from Russia. Import value was PLN 31,582,138 k (EUR 7,173,623 k), which constituted 37.68% of total mineral raw material imports value for Poland. The 2nd place was occupied by Germany (10.18%; PLN 8,530,376 k, EUR 1,928,386 k) and 3rd place by Saudi Arabia (5.42%; PLN 4,539,598 k, EUR 1,028,335 k; Fig. 15.2.10). Total import value from these 3 countries amounted to PLN 44,652,113 k (EUR 10,130,344 k; 53.28% of total import value).

16. Resources of critical raw materials for the Polish and EU economies

S. Mazurek

Although the list of critical raw materials for the Polish economy (Galos *et al.*, 2020) does not differ significantly from the list of raw materials deemed (by the same authors) strategic for Polish economy, data provided below apply to the raw materials of the collective critical raw materials list for the European Union, published by the European Commission ("Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability". COM, 2020, 474 final), and for the Polish economy (Fig. 16.1, Tab. 16.1).

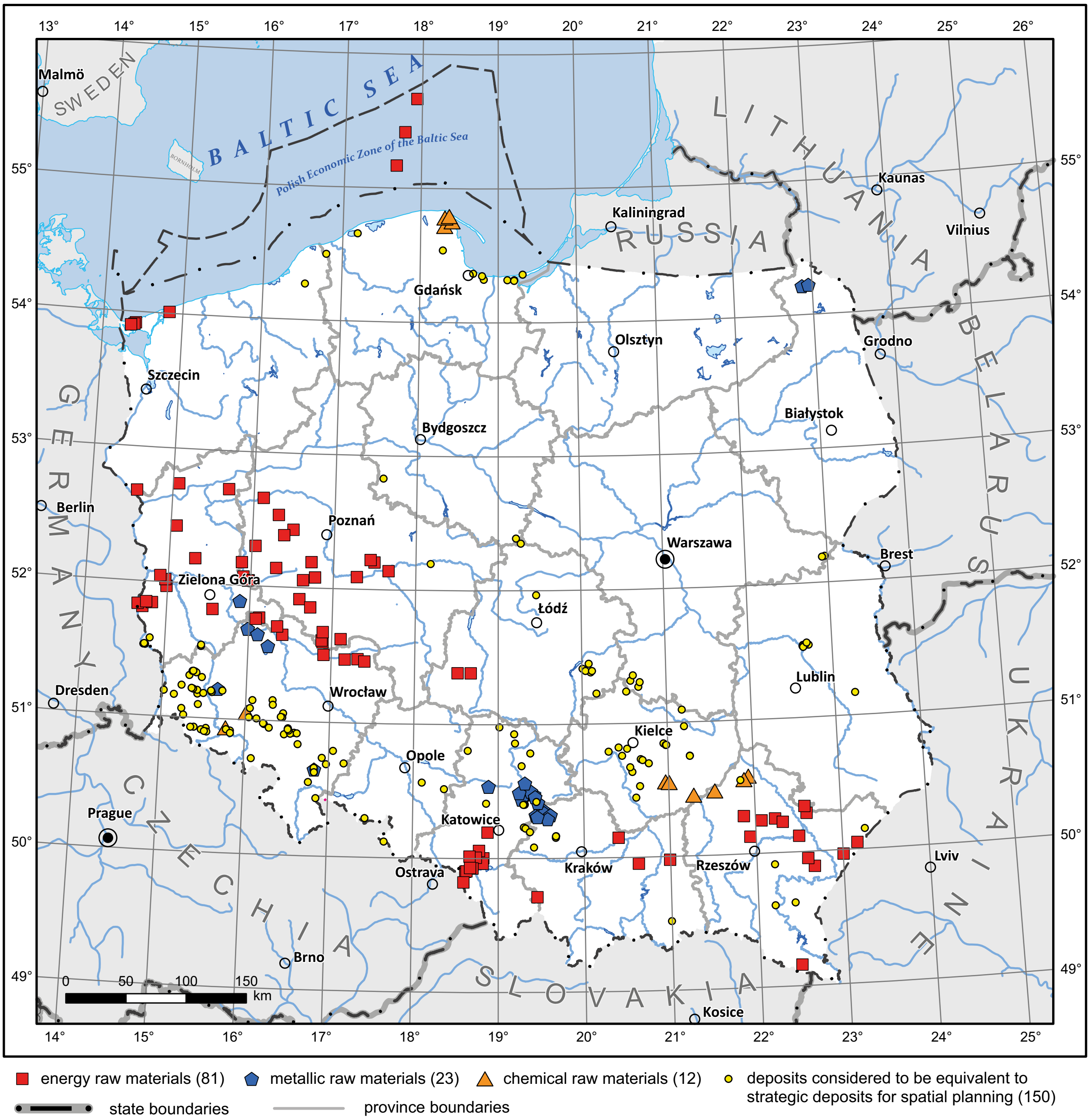


Figure 16.1. Location of strategic deposits in Poland

Deposits of the aforementioned raw materials were also presumed as strategic for the Polish economy, as well as having supranational importance. This list contains 96 deposits. Figure 16.2 shows the contribution of various types of deposits of critical raw materials to the total number of critical raw materials deposits. In Table 16.2 there are numbers of deposits presented, sorted by types of raw materials.

Table 16.1. Lists of critical raw materials for the Polish and EU economies

Critical raw materials for the Polish economy[1]	EU critical raw materials[2]	Selected uses by EU
Natural gas	–	–
Oil	–	–
Ambers	–	–
Bauxite	Bauxite	aluminum production
Antimony	Antimony	flame retardants, defense applications, lead-acid batteries
–	Barite	medical applications, radiation protection, chemical applications
–	Beryllium	electronic and communications equipment, automotive, aero-space and defense components
–	Bismuth	pharmaceutical and animal feed industries, medical applications, low-melting point alloys
–	Borate	high performance glass, fertilizers, permanent magnets
Chromium	–	–
–	Cobalt	batteries, super alloys catalysts, magnets
Coking coal	Coking coal	coke for steel, carbon fibers, battery electrodes
–	Fluorspar	steel and iron making, refrigeration and air-conditioning, aluminum making and other metallurgy
–	Gallium	semiconductors, photovoltaics
–	Germanium	optical fibers and infrared optics, solar cells for satellites, polymerization catalysts
Graphite (natural)	Graphite (natural)	batteries, refractories for steelmaking
–	Hafnium	super alloys, control rods for nuclear plants, refractory ceramics
Rare Earth Elements	Heavy Rare Earth Elements	permanent magnets for electric motors and electricity generators, lighting phosphors, catalysts, batteries, glass and ceramics
	Light Rare Earth Elements	
–	Indium	flat panel displays, photovoltaic cells and photonics, solder
–	Lithium	batteries, glass and ceramics, steel and aluminum metallurgy
Magnesium	Magnesium	lightweight alloys for automotive, electronics, packaging or construction, desulfurization agent in steelmaking
Manganese	–	–
Molybdenum	–	–
–	Niobium	high-strength steel and super alloys for transportation and infrastructure, high-tech applications (capacitors, superconducting magnets, etc.)
Platinum Group Metals	Platinum Group Metals	chemical and automotive catalysts, fuel cells, electronic applications
Phosphate rock	Phosphate rock	mineral fertilizer, phosphorus compounds
Phosphorus	Phosphorus	chemical and defense applications
–	Scandium	solid oxide fuel cells, lightweight alloys
Silicon metal	Silicon metal	semiconductors, photovoltaics, electronic components, silicones

Table 16.1. Cont.

Critical raw materials for the Polish economy[1]	EU critical raw materials[2]	Selected uses by EU
–	Strontium	ceramic magnets, aluminum alloys, medical applications, pyrotechnics
Tungsten	Tungsten	alloys e.g. for aeronautics, space, defense, electrical technology, milling, cutting and mining tools
–	Vanadium	high-strength-low-alloys for e.g. aeronautics, space, nuclear reactors, chemical catalysts

[1] According to: Galos *et al.* (2020).
[2] According to: "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability". COM (2020) 474 final.

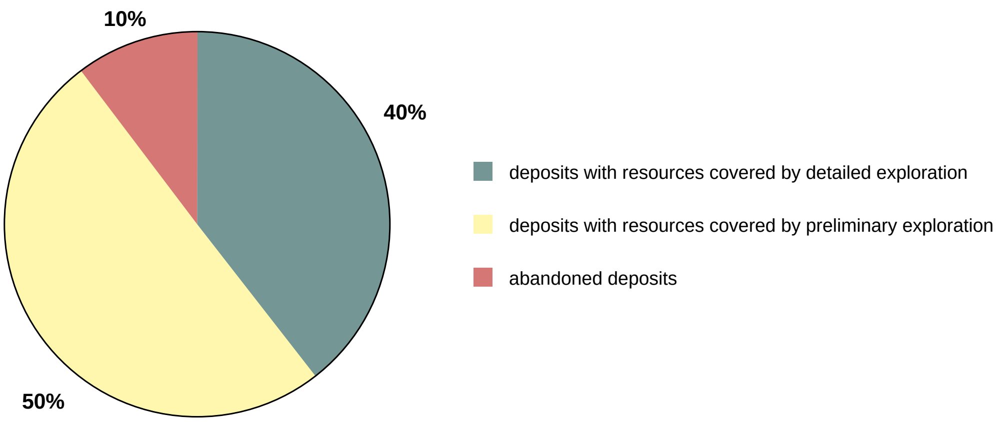


Figure 16.2. Types of undeveloped deposits for critical raw materials in Poland

According to: "The balance of mineral resources deposits in Poland as of 31 XII 2019" (in Polish: Szuflicki *et al.*, eds., 2020)

Table 16.2. Number of deposits by types of raw materials

Name of raw materials/type of deposit	Number of undeveloped deposits
Barites	5
Natural gas	58
Sand with REE	1
Oil	7
Mo-W-Cu	1
Fe-Ti-V	2
Coking coal	22

According to: "The balance of mineral resources deposits in Poland as of 31 XII 2019" (in Polish: Szuflicki *et al.*, eds., 2020)

17. Anthropogenic mining objects national inventory program for raw materials from secondary sources

S. Mazurek

In the Polish law according to the GML, anthropogenic accumulations of useful mineral components are not considered as deposits as they do not meet a requirement of a statutory definition which recognizes only natural accumulations as deposits. However, in the past, the legal status of accumulations varied, therefore in the industry the term "anthropogenic deposit" still exists – this term has is well-established despite a lack of a statutory definition.

Studies of the economic use of raw materials recycled from mining waste, together with an assessment of their impact on the natural environment, were commenced by PGI-NRI in the 20th century. First inventory work and mining waste studies on a regional scale were carried out in the Lower Silesian region.

Data sources for such work were:

- objects documented in the past, on an analogous basis as geological documentation of deposits – e.g. in the PGI-NRI Central Geological Database (CBDG) there is collected information on 23 geological documentations of Zn and Pb waste dumps and ponds from the 1954–1972 period, containing decisions by the Commission of Mineral Resources as the central body verifying geological documentations of deposits in Poland in that time (e.g. Wilga, Nosal, 1974);
- specialist elaborations other than documentation, e.g. industry catalogs;
- cross-sectional and task publications;
- regional monographs;
- documents remaining after mining plants closed in the 20th century;
- archival historical data (before the World War II) from archives;
- fieldwork by the Polish Geological Survey;
- chemical analyzes and special research (XRD, sections, microprobe etc.).

Inventory work, based on archival cartographic materials and field verification, in the past covered larger mining dumps, ponds and disposals, including dumps of overburden rocks and mining waste around active raw materials deposits formed contemporarily (Sroga, 1995, 1997). In the said inventory (and in inventories conducted in the following years) mineral waste were discarded together with municipal and industrial waste on the dumps and landfills in a way preventing their economic recycling, were excluded from it. There was a catalogue elaborated, containing 350 objects of raw materials from waste from the Lower Silesian region, together with a map in the 1:200,000 scale.

To the order of the Chief Environmental Inspectorate, the PGI-NRI elaborated the methodology of preparing a list of the objects of mining wastes disposals and of mineral studies of wastes materials in the environmental aspect (Fajfer *et al.*, 2010). According to this methodology, which was considered as a reference for the Chief Inspectorate of Environmental Protection, there was a list elaborated, of the most environmentally disruptive objects in southern Poland (the Upper and Lower Silesian regions), together with studies of the impact of select objects on the natural environment (soil, water, and air aspects were considered; Fajfer, ed., 2012).

The next phase of the inventory work (regarding raw materials) was carried out in the 2013–2017 period, in the Sudety Mts., which is the region in which the greatest accumulation of old exploitation dumps and ponds have been recorded. This work was carried out in detail, according to a standardized scheme, containing 12 thematic blocks (e.g. location, object dimensions, user, area purpose, waste characteristics, hydrogeological and geotechnical conditions, current state of object development and its neighborhood).

Very important – regarding the economic usage of waste – are data on an object and its neighboring infrastructure and environmental protection in the area. All the collected information are the basis for establishing the open-access geological database called HAŁDY, implemented into the CBDG. The database covers 4 spatial layers, 23 attribute tables, 12 dictionary tables, and allows the user to generate information thematicallyblocked or as individual inquires (Sroga *et al.*, 2018). The database is being updated as it absorbs new study results or based on changes of legal-environmental circumstances.

Rows (120 dictionary or descriptive data for all objects) of the database HAŁDY are grouped within the following thematic blocks:

- general data (name, object type, raw material type, area, volume);
- formal-planning data (owner/user, object in urban plans);
- waste characteristics (waste code, lithology, granulation, features);
- object and its neighboring morphology;
- current object status (state of development, waste exploitation);
- geo-technical data (geological structure of a basement, geo-dynamic occurrences, drainage);
- hydrogeological conditions (flooding, watercourses, aquifers, Major Groundwater Reservoirs);
- development in the area (forests, arable land, wasteland, building);
- environmental protection (national and landscape parks, protected landscape areas, Nature 2000 sites);
- object and its neighboring infrastructure (road, railways, power lines, buildings);
- object and its neighboring mining infrastructure (abandoned shafts, drift mines, other facilities);
- geo-dynamic occurrences in a neighborhood (depressions, erosion, faults);
- historical outline of an object;
- references used.

In the 2019–2020 period, there were other objects were put into the database and 2 new information layers were elaborated:

- object categorization regarding their natural environment and human health,
- categorization of the economic usage of waste material.

There were also objects selected for permanent monitoring and/or legal protection. Until the end of February 2022 database HAŁDY (publically available through the Internet browser – https://cbdgportal.pgi.gov.pl/haldy; Fig. 17.1, Plate 9) contained information on 1358 old mining objects in Poland.

In the last 3 years, inventory and exploration work have been extended to the entire area of Poland, covering former and current mining regions – both of metal ores and energy, chemical and rock raw materials – mainly within the Śląskie and the Małopolskie, Świętokrzyskie voivodeships, as well as the Sudetic Foreland. The largest and most characteristic, object located in the Polish Lowland has also been inventoried. Studies of particular objects are being carried out according to the methodology used up till now in the Sudety Mts. dumps that is by using a numerical model for the area. Field observations and objects sampling are still the main tools. There have been more than 700 further objects examined so far, mainly connected with hard coal, iron ore and zinc-lead ore mining, and rock raw materials. Fieldwork is being continued, and inventory covers nearly 1,400 objects in total. It is expected that the complete database to be publically available at the start of 2022.

As anthropogenic accumulations can also be treated as anthropogenic deposits (not in the legal sense, but in a factual sense), there will be (2021/2022) an assessment prepared for their utility in the economy, regarding the characteristics of selected objects on a basis of available archive data and information of current sampling, and on possibilities of raw material utility from selected objects. An indication of the necessary norms to be met by a raw material in a particular group will be prepared, together with studies essential for establishing the raw material's utility in select industries, and an elaboration of methodology for object identifications for anthropogenic accumulations development.

Anthropogenic objects are also a valuable source of information on primary deposits. Chemical analyzes of mineralogical components (e.g. XRD, micro-petrography) the identification of primary deposit components, which were not known or used in the old days, whereas they are valuable raw materials in 21st century. For this purpose, there have been about 1,000 analyzes and studies carried out. The important is also the fact if these primary deposits had been depleted in total, or if they continue deeper into the formation and their exploitation covered only a part of an orogen below groundwater level.

For address these issues, there has been a wide range of geophysics studies carried out in select regions where poly-metallic ore mining took place in the past, in the surroundings of old shafts and drift mines:

- 62 ERT and IP profiles of a total length of 31.7 km,
- 2,617 magnetic points along 42 profiles,
- 804 gamma-spectrometric points along 14 profiles,
- one seismic profile,
- one gravimetric profile.

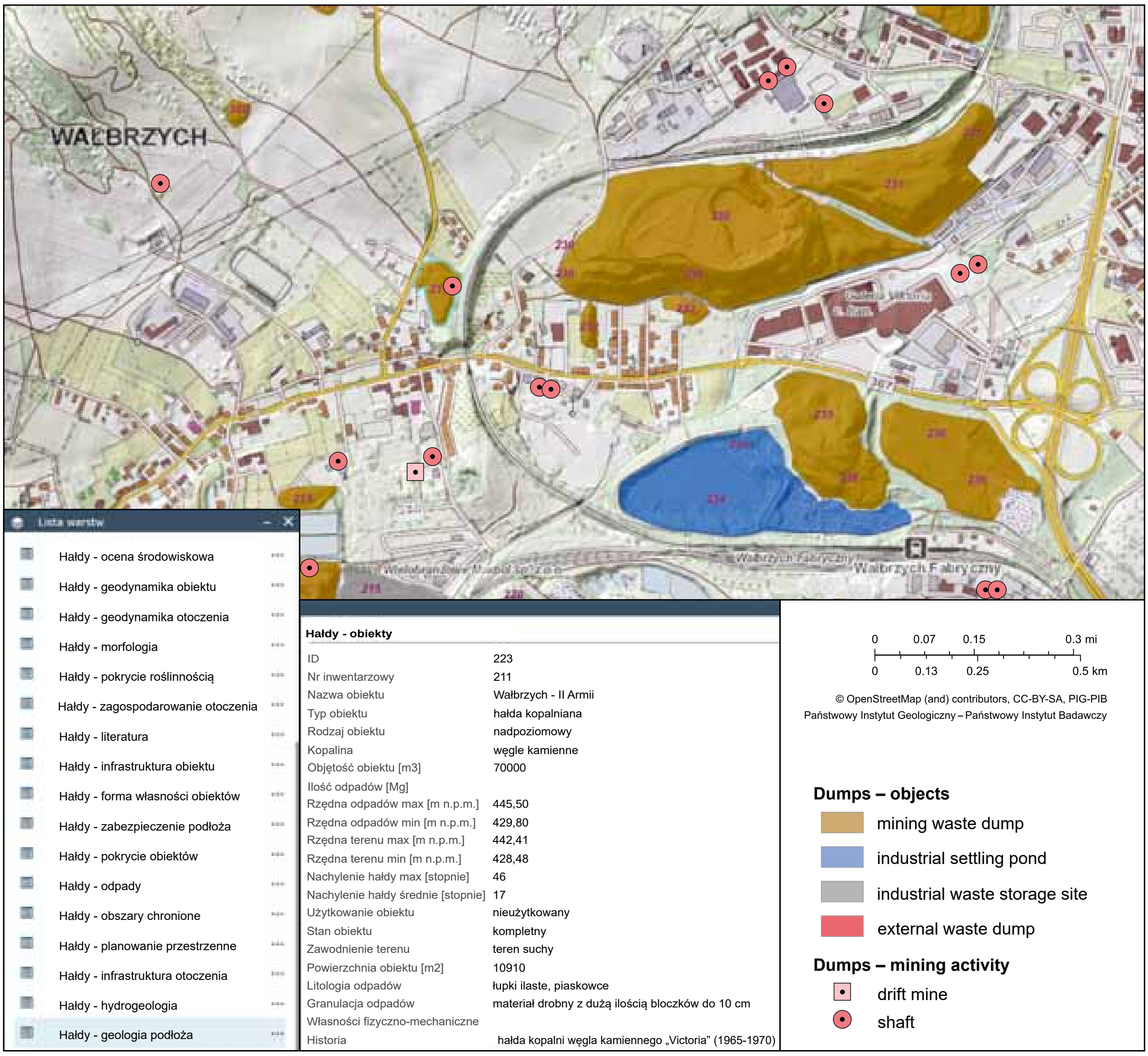


Figure 17.1. Object details in the database HAŁDY (https://cbdgportal.pgi.gov.pl/haldy)

There are also 18 boreholes planned, which had a geological work projects have been elaborated.

Dumps and ponds remaining after mining and raw materials processing, can also be the subject of market turnover – they are a part of a land property and can be a subject of market turnover similarly to land properties. The most important requirements for anthropogenic geological-mining asset are contained in updated in 2021 POLVAL code and regard to:

- definitions of mineral anthropogenic resources,
- geological documentation according to documentations of natural deposits,
- the owner of the anthropogenic deposit,
- an exploitation plan for the anthropogenic deposit.

Valuation of these asset (anthropogenic resources) by appraisers of raw material deposits, on a basis of the updated POLVAL code (Byrska-Rąpała *et al.*, 2019), is a relevant and simple basis for:

- undertaking economically justified exploitation of dumps and ponds,
- enabling the market turnover of such asset,
- establishing of buffers for these asset,
- making a commitment on these asset.

In 2022, the Polish Geological Survey, on the order from the National Fund for Environmental Protection and Water Management, plans to complete an environmental assessment for dumps inventoried during the last several years.

In conclusion of the work by the PSG, carried out by PGI-NRI, it should be stated that anthropogenic mineral objects are of significant importance for the national mineral economy, both directly for the current usage and indirectly – for prospecting-economic geology. A broad spectrum of implemented work does not mean that the given issue is resolved – on the contrary, the collected data indicate that further work should be carried out in parallel – on the utility of raw materials from industry dumps and pointing these for further prospecting for metals significant for the economy of the 21st century.

Completed work, studies and analyses should not only improve the state of knowledge on secondary raw material sources on a domestic scale, but also should be a contribution for proper legal regulation of the status of a mineral anthropogenic object. Obtained knowledge should be useful for creating and maintaining an ongoing object register in a manner similar to the methodology used for the domestic balance of mineral resource deposits.

References

ALEKSANDROWSKI P., 2020a – Prowincje tektoniczne Polski. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 40. PIG-PIB, Warszawa.

ALEKSANDROWSKI P., 2020b – Struktury mezozoiczne (staroalpejskie). *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 42. PIG-PIB, Warszawa.

ALEKSANDROWSKI P., BUŁA Z., 2020a – Struktury wczesnopaleozoiczne i późnoproterozoiczne (kaledońskie, sandomierskie i kadomskie). *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 44. PIG-PIB, Warszawa.

ALEKSANDROWSKI P., BUŁA Z., 2020b – Struktury późnopaleozoiczne (waryscyjskie). *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 43. PIG-PIB, Warszawa.

BECKER A., SZULC J., 2020 – Trias. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 70–71. PIG-PIB, Warszawa.

BP Statistical Review of world Energy, 70th Edition, 2021. Centre for Energy Economics Research and Policy, Heriot-Watt University, United Kingdom.

BRAŃSKI P., 2020 – Kopaliny bentonitowe i zeolitowo-bentonitowe (bentonite and bentonites clays, zeolite and zeolite clays). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 362–364. PIG-PIB, Warszawa.

BRZEZIŃSKI D., 2020 – Wapienie i margle przemysłowe – wapienie i margle dla przemysłu cementowego i wapienniczego (limestones and marls for cement and lime industry). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 276–281. PIG-PIB, Warszawa.

BRZEZIŃSKI D., GALOS K., 2020 – Kwarcyty, piaskowce kwarcytowe i łupki ogniotrwałe (quartzite, quartzitic sandstone and quartzitic schist). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 305–308. PIG-PIB, Warszawa.

BRZEZIŃSKI D., MIŚKIEWICZ W., 2020 – Kamienie łamane i bloczne (crushed and dimension stones), kamienie drogowe i budowlane (road and building stones). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 297–304. PIG-PIB, Warszawa.

BYRSKA-RĄPAŁA A., DZIEŻA J., GALOS K., GLAPA W., KICKI J., MAZUREK S., NIEĆ M., PAULO A., PIETKIEWICZ P., SADECKI Z., SAŁUGA P., STRZELSKA-SMAKOWSKA B., UBERMAN R., UBERMAN R., WIRTH H., 2019 – Polish Code for the Valuation Of Mineral Assets (The POLVAL Code 2008) [http://polval.org.pl/wp-content/uploads/2019/05/1-wersja-angielska.pdf]. Polish Association of Mineral Asset Valuators, Kraków.

CZAPOWSKI G., BUKOWSKI K., 2011 – Sól kamienna i sole potasowo-magnezowe. *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31 XII 2009 r. (eds. Wołkowicz S., Smakowski T., Speczik S.): 133–142. Ministerstwo Środowiska, Warszawa.

CZAPOWSKI G., BUKOWSKI K., 2015 – Mapy wystąpień zasobów perspektywicznych soli w Polsce jako narzędzie w projektowaniu przyszłego zagospodarowania złóż kopalin. *Maps of salt prospective resources in Poland as a tool of the future management of salt occurrences* [in Polish with English abstract]. *Przegląd Solny*, 11: 5–31.

CZAPOWSKI G., BUKOWSKI K., GĄSIEWICZ A., SADŁOWSKA K., 2015 – Obszary perspektywicznych wystąpień i zasoby przewidywane surowców chemicznych Polski na mapach w skali 1 : 200 000 – sól kamienna, sole potasowo-magnezowe i siarka. *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* [in Polish with English abstract]. *Przegląd Geologiczny*, 63 (9): 561–571.

CZAPOWSKI G., BUKOWSKI K., MAZUREK S., 2020 – Sól kamienna (rock salt, salt, halites) i sole potasowo-magnezowe (potash salts, potassium salts, potassium-magnessium salts). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 218–232. PIG-PIB, Warszawa.

DOWGIAŁŁO J., PACZYŃSKI B., 2002 – Podział regionalny wód leczniczych Polski. *In:* Ocena zasobów dyspozycyjnych wód potencjalnie leczniczych. Poradnik metodyczny (ed. Paczyński B.): 16–24. PIG, Warszawa.

DOWGIAŁŁO J., KLECZKOWSKI A.S., MACIOSZCZYK T., RÓŻKOWSKI A. (eds.), 2002 – Słownik hydrogeologiczny. PIG, Warszawa.

FAJFER J. (ed.), 2012 – Spis obiektów unieszkodliwiania odpadów wydobywczych oraz opuszczonych obiektów unieszkodliwiania odpadów wydobywczych, które wywierają negatywny wpływ na środowisko. Główny Inspektorat Ochrony Środowiska, Warszawa. [not-published]

FAJFER J., KRIEGER W., ROLKA M., ANTOLAK O., 2010 – Opracowanie metodyki wykonania spisu zamkniętych obiektów unieszkodliwiania odpadów wydobywczych oraz opuszczonych obiektów unieszkodliwiania odpadów wydobywczych, które wywierają negatywny wpływ na środowisko. PIG-PIB, Sosnowiec. [not-published]

FELDMAN-OLSZEWSKA A., KIERSNOWSKI H., PERYT T., PACZEŚNA J., LASKOWICZ R., JANAS M., GŁUSZYŃSKI A., WAŚKIEWICZ K., 2020a – Ropa naftowa (crude oil), gaz ziemny (natural gas), kondensat ropno-gazowy (condensate). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 49–69. PIG-PIB, Warszawa.

FELDMAN-OLSZEWSKA A., PIEŃKOWSKI G., WIERZBOWSKI A., 2020b – Jura. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 72–73. PIG-PIB, Warszawa.

FELTER A., 2020 – Solanki (brine). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 395–399. PIG-PIB, Warszawa.

GALOS K., 2020a – Piaski szklarskie (glass sand), piaskowce szklarskie (glass sandstone), piaski kwarcowe dla przemysłu szklarskiego (quartz sand for glass industry). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 317–320. PIG-PIB, Warszawa.

GALOS K., 2020b – Iły biało wypalające się (white-firing clay, ball clay), kamionkowe (stoneware clay, ceramic clay) i ogniotrwałe (refractory clay, flint clay). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 335–339. PIG-PIB, Warszawa.

GALOS K., MIŚKIEWICZ W., 2020 – Piaski kwarcowe do produkcji betonów komórkowych (quartz sand for cellular concrete manufacture), piaski kwarcowe do produkcji wyrobów wapienno-piaskowych (quartz sand for lime-sand products manufacture), piaski podsadzkowe (filling sand). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 309–313. PIG-PIB, Warszawa.

GALOS K., SMAKOWSKI T., 2020 – Dolomity przemysłowe (industrial dolomite), dolomity ceramiczne i szklarskie (dolomite for ceramics and glass), dolomity dla hutnictwa i materiałów ogniotrwałych (smelter and refractory dolomite), marmury dolomitowe (dolomitic marble). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 345–349. PIG-PIB, Warszawa.

GALOS K., LEWICKA E., BURKOWICZ A., GUZIK K., KOT-NIEWIADOMSKA A., KAMYK J., SZLUGAJ J., 2020 – Approach to identification and classification of the key, strategic and critical minerals important for the mineral security of Poland. *Resources Policy*, 70.

GAŁĄZKA D., NOWACKI Ł., 2020 – Czwartorzęd. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 78–79. PIG-PIB, Warszawa.

GAŁĄZKA D., NOWACKI Ł., KASIŃSKI J.R., JASIONOWSKI M., MALATA T., BECKER A., 2020 – Paleogen i neogen. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 76–77. PIG-PIB, Warszawa.

GAWEŁ A., 1953 – Jaspisy z diabazu Niedźwiedziej Góry koło Krzeszowic. Acta Geologica Polonica, III (1): 1–32.

GĄSIEWICZ A., 2020 – Siarka, siarka rodzima (native sulphur). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 213–217. PIG-PIB, Warszawa.

GIENTKA M., MALON A., TYMIŃSKI M. (eds.), 2007 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XII 2006 r. PIG, Warszawa.

GIENTKA M., MALON A., DYLĄG J. (eds.), 2008 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XII 2007 r. PIG, Warszawa.

GÓRECKI W. (ed.), 2006 – Atlas zasobów geotermalnych na Niżu Polskim. Formacje mezozoiku. *Atlas of geothermal resources in the Polish Lowlands. Mesozoic formations* [in Polish and English]. AGH, Ministry of Environment, NFEP&WM in Warsaw, Kraków.

GÓRECKI W. (ed.), 2011 – Atlas zasobów wód i energii geotermalnej Karpat Zachodnich. *Atlas of geothermal waters and energy resources in the Western Carpathians* [in Polish and English]. AGH, Ministry of Environment, NFEP&WM in Warsaw, Kraków.

GÓRECKI W. (ed.), 2012 – Atlas geotermalny zapadliska przedkarpackiego. *Geothermal atlas of the Carpathian Foredeep* [in Polish and English]. AGH, Ministerstwo Nauki i Szkolnictwa Wyższego, NCBiR, Kraków.

GÓRECKI W. (ed.), 2013 – Atlas geotermalny Karpat wschodnich. *Geothermal atlas of the Eastern Carpathians* [in Polish and English]. AGH, Ministry of Science and Higher Education Republic of Poland, the National Science Centre, Kraków.

HADRO J., JURECZKA J., 2020 – Metan z pokładów węgla (coalbed methane). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 113–119. PIG-PIB, Warszawa.

HAJTO M., 2016 – Międzynarodowa klasyfikacja zasobów geotermalnych (UNFC-2009) na tle polskich zasad klasyfikacji i metodyki szacowania zasobów geotermalnych. *United Nations Framework Classification of Geothermal Resources (UNFC-2009) against the Polish classification and methodology of geothermal resources assessment* [in Polish with English abstract]. *Technika Poszukiwań Geologicznych. Geotermia, Zrównoważony Rozwój*, 55 (1): 129–142.

HAJTO M., 2018 – Potencjał geotermalny Polski oraz możliwości adaptacji międzynarodowej klasyfikacji zasobów geotermalnych UNFC-2009. *Geothermal potential of Poland and the possibility of adapting the UNFC-2009 international classification of geothermal resources* [in Polish with English abstract]. *Nafta-Gaz*, 12/2018: 898–904.

HEFLIK W., 1974 – Nefryt. *Nauka dla wszystkich*, 229. PAN, Kraków.

HEFLIK W., 2010 – O niektórych kamieniach ozdobnych Dolnego Śląska i ich znaczeniu w rozwoju kultury materialnej. *In: Dzieje górnictwa – element europejskiego dziedzictwa kultury* (eds. Zagożdżon P.P., Madziarz M.), 3: 139–148. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

HEFLIK W., PAWLIKOWSKI M., 1977 – Jaspisy z miejscowości Świerki koło Nowej Rudy na Dolnym Śląsku [in Polish with English summary]. *Przegląd Geologiczny*, 25 (5): 239–243.

JURECZKA J., IHNATOWICZ A., KOTLAREK P., KRIEGER W., MŁYNARCZYK M., 2020 – Węgiel kamienny (hard coal). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 99–112. PIG-PIB, Warszawa.

JURYS L., 2020 – Kreda jeziorna i gytia wapienna (lacustrine chalc). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 368–370. PIG-PIB, Warszawa.

KASIŃSKI J.R., PIWOCKI M., MAZUREK S., 2006 – Waloryzacja i ranking złóż węgla brunatnego w Polsce. *Valorization and ranking, list of lignite deposits in Poland* [in Polish with English abstract]. *Prace Państwowego Instytutu Geologicznego*, 187: 1–79.

KASIŃSKI J.R., MAZUREK S., MŁYNARCZYK M., 2020 – Węgiel brunatny (brown coal). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 84–98. PIG-PIB, Warszawa.

KIERSNOWSKI H., PERYT T., JASIONOWSKI M., SKOWROŃSKI L., 2020 – Perm. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 68–69. PIG-PIB, Warszawa.

KOSAKOWSKI P., KOTARBA M. J., PIESTRZYŃSKI A., SHOGENOVA A., WIĘCŁAW D., 2016 – Petroleum source rock evaluation of the Alum and Dictyonema Shales (Upper Cambrian–Lower Ordovician) in the Baltic Basin and Podlasie Depression (eastern Poland). *Int. J. Earth Sci.*, 106: 743–761.

KOZŁOWSKA O., SMAKOWSKI T., MIŚKIEWICZ W., 2020 – Kruszywo naturalne piaskowo-żwirowe (natural aggregates). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 258–275. PIG-PIB, Warszawa.

KRAMARSKA R., KASIŃSKI J.R., SŁODKOWSKA B., 2020 – Bursztyn, sukcynit (amber, succinate). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 371–377. PIG-PIB, Warszawa.

KULCZYCKI Z., SOWA A., 2010 – Gospodarka zasobami złóż węgla kamiennego. *Górnictwo i Geoinżynieria*, 34 (3), 83–100.

LESZCZYŃSKI K., MALATA T., 2020 – Kreda. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 74–75. PIG-PIB, Warszawa.

LEWICKA E., 2020 – Kaoliny (kaolin). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 340–344. PIG-PIB, Warszawa.

ŁOBOS K., SACHANBIŃSKI M., PAWLIK T., 2008 – Nefryt z Nasławic na Dolnym Śląsku. *Nephrite from Nasławice in Lower Silesia (SW Poland)* [in Polish with English abstract]. *Przegląd Geologiczny*, 56 (11): 991–999.

ŁUGIEWICZ-MOŁAS I., KWARCIŃSKI J., PONIKOWSKA M., 2020 – Hel (helium). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 387–389. PIG-PIB, Warszawa.

MANECKI A., 2015 – Agaty i krzemienie. Geneza piękna – piękno genezy. *Nauka dla ciekawych*, 7. Wyd. AGH, Kraków.

MIKULSKI S.Z., MAŁEK R., 2020 – Rudy cyny (tin ores). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 162–167. PIG-PIB, Warszawa.

MIKULSKI S.Z., OSZCZEPALSKI S., 2020 – Rudy złota (gold ores). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 174–187. PIG-PIB, Warszawa.

MIKULSKI S.Z., RETMAN W., 2020 – Rudy cynku i ołowiu (zinc and lead ores). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 152–161. PIG-PIB, Warszawa.

MIKULSKI S.Z., SADŁOWSKA K., 2020 – Rudy niklu (nickel ores). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 168–173. PIG-PIB, Warszawa.

MIKULSKI S.Z., OSZCZEPALSKI S., MARKOWIAK M., 2012 – Występowanie i zasoby perspektywiczne rud molibdenu i wolframu w Polsce. *The occurrence and prospective resources of molybdenum and tungsten ores in Poland* [in Polish with English abstract]. *Biuletyn Państwowego Instytutu Geologicznego*, 448: 297–314.

MIKULSKI S.Z., OSZCZEPALSKI S., SADŁOWSKA K., CHMIELEWSKI A., MAŁEK R., 2018 – Występowanie pierwiastków towarzyszących i krytycznych w wybranych udokumentowanych złożach rud Zn-Pb, Cu-Ag, Fe-Ti-V, Mo-Cu-W, Sn, Au-As i Ni w Polsce. *The occurrence of associated and critical elements in the selected documented Zn-Pb, Cu-Ag, Fe-Ti-V, Mo-Cu-W, Sn, Au-As and Ni deposits in Poland* [in Polish with English abstract]. *Biuletyn Państwowego Instytutu Geologicznego*, 472: 21–52.

MIKULSKI S.Z., OSZCZEPALSKI S., SADŁOWSKA K., CHMIELEWSKI A., MAŁEK R., 2020 – Trace Element Distributions in the Zn-Pb (Mississippi Valley-Type) and Cu-Ag (Kupferschiefer) Sediment-Hosted Deposits in Poland. *Minerals*, 10 (1), 75.

MIŁACZEWSKI L., WÓJCIK K., MATYJA H., 2020 – Dewon. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 64–65. PIG-PIB, Warszawa.

MINISTERSTWO KLIMATU I ŚRODOWISKA (MKiŚ), 2021 – Polityka energetyczna Polski do 2040 r. [https://bip.mos.gov.pl/fileadmin/user_upload/bip/strategie_plany_programy/Polityka_energetyczna_Polski/PEP2040_2021-02-02.pdf]. Warszawa.

MIŚKIEWICZ W., BRZEZIŃSKI D., KALINOWSKA A., STAWIEREJ J., 2021 – Piaski i żwiry. *In:* Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII 2020 r. (eds. Szuflicki M., Malon A., Tymiński M.): 152–405. PIG-PIB, Warszawa.

MIZERSKI W., WOŁKOWICZ K., AWDANKIEWICZ H., RZYMEŁKA J., 2020 – Krzemionkowe kopaliny przemysłu jubilerskiego (siliceous jewellery stones). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 378–381. PIG-PIB, Warszawa.

NAWROCKI J., BECKER A. (eds.), 2020 – Atlas Geologiczny Polski. PIG-PIB, Warszawa.

NIEĆ M., 2003 – Ocena geologiczno-gospodarcza złóż wanadonośnych rud tytanomagnetytowych masywu suwalskiego. *Geo-economic evaluation of vanadiferous titanomagnetite deposits in Suwałki massif in Poland* [in Polish with English abstract]. *Gospodarka Surowcami Mineralnymi*, 19 (2): 5–28.

NIEĆ M., 2009 – Polska i międzynarodowa ramowa klasyfikacja zasobów (UNFC) złóż kopalin stałych i węglowodorów – podobieństwa i różnice. *Polish and United Nations Framework Classification of Resources (UNFC) – similarities and differences* [in Polish with English abstract]. *Górnictwo Odkrywkowe*, 50 (2/3): 50–57.

NIEĆ M., 2010a – Międzynarodowe klasyfikacje zasobów złóż kopalin. *Górnictwo i Geoinżynieria*, 34 (3): 33–49.

NIEĆ M., 2010b – Mode of reporting resources and reserves in Poland and relationship to UNFC, CRIRSCO and PRMS classifications. International Workshop on United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) – Theory and Practice. PGI-NRI, Warsaw. [not-published]

NIEĆ M., 2012 – Metody dokumentowania złóż kopalin stałych. Część IV. Szacowanie zasobów. Ministerstwo Środowiska, Kraków.

NIEĆ M., 2016 – Porównanie klasyfikacji zasobów węglowodorów: polskiej, PRMS, UNFC i stosowanej w dokumentowaniu złóż niekonwencjonalnych. *Hydrocarbon resources classification: Polish, PRMS, UNFC and applied to shale gas. A comparison* [in Polish with English abstract]. *Nafta-Gaz*, 9/2016: 713–721.

NIEĆ M., GALOS K., 2015 – Cele, zadania i kierunki polityki surowcowej [prezentacja podczas Debaty pod auspicjami Prezesa Polskiej Akademii Nauk "Problemy polityki i bezpieczeństwa surowcowego Polski – wymagania dla społeczności naukowej"; https://docplayer.pl/45423750-Cele-zadania-i-kierunki-polityki-surowcowej-marek-niec-krzysztof-galos.html].

NIEĆ M., MŁYNARCZYK M., 2014 – Gospodarowanie zasobami węgla kamiennego w Polsce. *Studia, rozprawy, monografie*, 187. Wyd. IGSMiE PAN, Kraków.

NIŚKIEWICZ J., 1982 – Geologiczne warunki występowania chryzoprazu i pokrewnych kamieni ozdobnych w masywie Szklar (Dolny Śląsk). *Geological setting of the occurrence of chrysoprase and related gem-stones in the Szklary Massif, Lower Silesia* [in Polish with English abstract and summary]. *Geologia Sudetica*, 17 (1/2): 125–139.

OSZCZEPALSKI S., CHEMIELEWSKI A., 2015 – Zasoby przewidywane surowców metalicznych Polski na mapie w skali 1 : 200 000 – miedź, srebro, złoto, platyna i pallad w utworach cechsztyńskiej serii miedzionośnej. *Predicted metallic resources in Poland presented on the prospective maps at scale 1 : 200 000 – copper, silver, gold, platinum and palladium in the Kupferschiefer oreseries* [in Polish with English abstract]. *Przegląd Geologiczny*, 63 (9): 535-545. Warsaw.

OSZCZEPALSKI S., RYDZEWSKI A., 1997 – Atlas metalogeniczny cechsztyńskiej serii miedzionośnej w Polsce. PAE S.A., Warszawa.

OSZCZEPALSKI S., SPECZIK S., MAŁECKA K., CHMIELEWSKI A., 2016 – Prospective copper resources in Poland. *Gospodarka Surowcami Mineralnymi*, 32 (2): 5–30.

OSZCZEPALSKI S., SPECZIK S., ZIELIŃSKI K., CHMIELEWSKI A., 2019 – The Kupferschiefer Deposits and Prospects in SW Poland: Past, Present and Future. *Minerals*, 9 (592): 1–42.

OSZCZEPALSKI S., MARKOWIAK M., CHMIELEWSKI A., 2020 – Rudy miedzi i srebra (copper and silver ores). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 127–151. PIG-PIB, Warszawa.

PACZEŚNA J., BUŁA Z., 2020 – Ediakar. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 56–57. PIG-PIB, Warszawa.

PACZEŚNA J., SZCZEPANIK Z., ŻYLIŃSKA A., BUŁA Z., 2020 – Kambr. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 58–59. PIG-PIB, Warszawa.

PACZYŃSKI B., PŁOCHNIEWSKI Z., 1996 – Wody mineralne i lecznicze Polski. PIG-PIB, Warszawa.

PIEŃKOWSKI G., KRAMARSKA R., 2017 – Mapa geologiczna Polski bez utworów kenozoiku 1:2 500 000. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 26–27. PIG-PIB, Warszawa.

PODHALAŃSKA T., WAKSMUNDZKA M.I., BECKER A., ROSZKOWSKA-REMIN J., DYRKA I., FELDMAN-OLSZEWSKA A., GŁUSZYŃSKI A., GROTEK I., JANAS M., KARCZ P., NOWAK G., PACZEŚNA J., ROMAN M., SIKORSKA-JAWOROWSKA M., KUBERSKA M., KOZŁOWSKA A., SOBIEŃ K., 2016 – Strefy perspektywiczne występowania niekonwencjonalnych
złóż węglowodorów w kambryjskich, ordowickich, sylurskich i karbońskich kompleksach skalnych Polski – integracja wyników badań. *Prospective zones for unconventional hydrocarbon resources in Cambrian, Ordovician, Silurian and Carboniferous rocks of Poland – integration of the research results* [in Polish with English abstract]. *Przegląd Geologiczny*, 64 (12): 1008–1021.

PODHALAŃSKA T., ADAMCZAK-BIAŁY T., BECKER A., DYRKA I., FELDMAN-OLSZEWSKA A., GŁUSZYŃSKI A., GROTEK I., JANAS M., JARMOŁOWICZ-SZULC K., JACHOWICZ M., KARCZ P., KLIMUSZKO E., KOZŁOWSKA A., KRZYŻAK E., KUBERSKA A., NOWAK G., PACHYTEL R., PACZEŚNA J., ROMAN M., SIKORSKA-JAWOROWSKA M., SKOWROŃSKI L., SOBIEŃ K., TRELA W., TRZEPIERCZYŃSKA A., WAKSMUNDZKA M.I., WOŁKOWICZ K., WÓJCICKI A., 2018 – Rozpoznanie stref perspektywicznych dla występowania niekonwencjonalnych złóż węglowodorów w Polsce, stałe zadanie psg, etap II. Opracowanie końcowe z realizacji projektu. Narodowe Archiwum Geologiczne, Item No 9051/2019. PIG-PIB, Warszawa.

PODHALAŃSKA T.. FELDMAN-OLSZEWSKA A., ROSZKOWSKA-REMIN J., JANAS M., PACHYTEL R., GŁUSZYŃSKI A., ROMAN M., 2020a – Prospective zones of unconventional hydrocarbon reservoirs in the Cambrian, Ordovician and Silurian shale formations of the East European Craton marginal zone in Poland. *Geological Quarterly*, 64 (2): 342–376.

PODHALAŃSKA T., TRELA W., LIS P., BUŁA Z., 2020b – Sylur. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 62–63. PIG-PIB, Warszawa.

POLISH Geological Institute – National Research Institute (PGI-NRI), 2012 – Assessment of shale gas and shale oil resources of the Lower Paleozoic in Baltic-Podlasie-Lublin Basin in Poland. The first report. Warsaw.

POPRAWA P., 2010 – Potencjał występowania złóż gazu ziemnego w łupkach dolnego paleozoiku w basenie bałtyckim i lubelsko-podlaskim. *Shale gas potential of the Lower Palaeozoic complex in the Baltic and Lublin-Podlasie basins (Poland)* [in Polish with English abstract]. *Przegląd Geologiczny*, 58 (3): 226–249.

POPRAWA P., 2020 – Lower Paleozoic oil and gas shale in the Baltic-Podlasie-Lublin Basin (central and eastern Europe) – a review. *Geological Quarterly*, 64 (3): 515–566.

PRZENIOSŁO S. (ed.), 1990–2005 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XII [1988–2004 r.]. PIG-PIB, Warszawa.

PRZENIOSŁO S., MALON A. (eds.), 2006 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XX 2005 r. PIG-PIB, Warszawa.

PRZYLIBSKI T.A. (ed.), 2007 – Studium możliwości rozpoznania nowych wystąpień wód zmineralizowanych, swoistych i termalnych na obszarze bloku przedsudeckiego. *Raporty Instytutu Górniczego*, Series SPR 1-11/S-5/2007. Politechnika Wrocławska, Wroclaw.

RAJCHEL L., 2000 – Źródła wód siarczkowych w Karpatach polskich. *Springs of sulphurous waters in the Polish Carpathians* [in Polish with English abstract]. *Geologia*, 26 (3): 309–373.

SACHANBIŃSKI M., 1985 – Chryzopraz. *Mineralogia Polonica*, 16 (1): 117–130.

SOBCZYK E.J., 2009 – Uciążliwość geologiczno-górniczych warunków eksploatacji węgla kamiennego i jej wpływ na gospodarkę złożem. *Studia, rozprawy, monografie*, 150. Wyd. IGSMiE PAN, Kraków.

SOCHA M., SKRZYPCZYK L., 2020 – Wody termalne (thermal water, geothermal water). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 405–409. PIG-PIB, Warszawa.

SOKOŁOWSKI J., SKRZYPCZYK L., 2020 – Wody lecznicze (therapeutic water, medicinal water). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 400–404. PIG-PIB, Warszawa.

SOKOŁOWSKI J., SKRZYPCZYK L., 2021 – Solanki, wody lecznicze i termalne. *In:* Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII 2020 r. (eds. Szuflicki M., Malon A., Tymiński M.): 488–505. PIG-PIB, Warszawa.

SROGA C., 1995 – Ewidencja i ocena wartości surowcowej hałd, wysypisk i osadników poeksploatacyjnych na obszarze Dolnego Śląska. PIG, Wrocław. [not-published]

SROGA C., 1997 – Mineralne surowce odpadowe Sudetów i Przedgórza Sudeckiego wraz z Mapą w skali 1 : 200 000. PIG, Warszawa.

SROGA C., 2020a – Baryt (barite, baryte) i fluoryt (fluorite, fluorspar). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 207–212. PIG-PIB, Warszawa.

SROGA C., 2020b – Magnezyty (magnesite). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 350–352. PIG-PIB, Warszawa.

SROGA C. LEWICKA E., 2020 – Kopaliny skaleniowe (feldspar, Na-feldspar, K-feldspar). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 329–334. PIG-PIB, Warszawa.

SROGA C., MIKULSKI S.Z., BOBIŃSKI W., ADAMSKI M., 2018 – Stare hałdy w Sudetach – nowa geobaza Państwowego Instytutu Geologicznego. *Old heaps in the Sudetes Mts. – a new geodatabase of the Polish Geological Institute* [in Polish with English abstract]. *Zeszyty Naukowe IGSMiE PAN*, 106: 147–162.

SZAMAŁEK K., MŁYNARCZYK M., 2017 – Geological and Mining Law. *In:* Mineral Resources of Poland (eds. Szamałek K., Szuflicki M., Malon A., Tymiński M.): 17. PIG-PIB, Warszawa.

SZAMAŁEK K., SZUFLICKI M., MALON A., TYMIŃSKI M. (eds.), 2017 – Mineral Resources of Poland. PIG-PIB, Warszawa.

SZAMAŁEK K., SZUFLICKI M., MIZERSKI W. (eds.), 2020 – Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. PIG-PIB, Warszawa.

SZCZYGIELSKI W., WALENTEK I., 2020 – Surowce ceramiki budowlanej (building ceramics raw materials), surowce do produkcji kruszyw ceramicznych i cementu (mineral raw materials for production of clay aggregates and cement clinker). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 239–256. PIG-PIB, Warszawa.

SZTROMWASSER E., GIEŁŻECKA-MĄDRY D., KUĆ P., 2020 – Gipsy i anhydryty (gypsum and anhydrite). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 282–296. PIG-PIB, Warszawa.

SZUFLICKI M., MALON A., TYMIŃSKI M. (eds.), 2011 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XII 2010 r. PIG-PIB, Warszawa.

SZUFLICKI M., MALON A., TYMIŃSKI M. (eds.), 2012–2021 – Bilans zasobów złóż kopalin w Polsce wg stanu na 31 XII [2011–2020 r.]. PIG-PIB, Warszawa.

TRELA W., MODLIŃSKI Z., BUŁA Z., 2020 – Ordowik. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 60–61. PIG-PIB, Warszawa.

UNECE, 2020 – United Nations Framework Classification for Resources Update 2019. ECE Energy Series No 61. Geneva.

WAKSMUNDZKA M.I., BUŁA Z., SKOMPSKI S., 2020 – Karbon. *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 66–67. PIG-PIB, Warszawa.

WIĘCŁAW D., KOTARBA M. J., KOSAKOWSKI P., KOWALSKI A., GROTEK I., 2010 – Habitat and hydrocarbon potential of the lower Paleozoic source rocks in the Polish part of the Baltic region. *Geological Quarterly*, 54 (2): 159–182.

WILGA H., NOSAL J., 1974 – Obliczenie zasobów materiału cynkowo-ołowiowego zwału pogórniczego C/HŁ-XIII w Piekarach Śląskich w kat. B, woj. Katowice, pow. Tarnowskie Góry, miejscowość Piekary Śląskie. Estimation of zinc-lead material resources of mining dump C/HŁ-XIII in Piekary Śląskie in category B, Katowice Voivodeship, Tarnowskie Góry county, Piekary Śląskie town [in Polish]. Narodowe Archiwum Geologiczne, Item No 10593 CUG. PIG-PIB, Warszawa.

WOŁKOWICZ K., 2020a – Kopaliny diatomitowe, diatomit (diatomaceous rock, diatomite). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 353–358. PIG-PIB, Warszawa.

WOŁKOWICZ K., 2020b – Ziemia krzemionkowa (siliceous earth). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 359–361. PIG-PIB, Warszawa.

WOŁKOWICZ K., SROGA C., 2020 – Kwarc żyłowy (vein quartz). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 325–328. PIG-PIB, Warszawa.

WOŁKOWICZ S., MALON A., TYMIŃSKI M. (eds.), 2009–2010 – Bilans zasobów kopalin i wód podziemnych w Polsce wg stanu na 31 XII [2008–2009 r.]. PIG-PIB, Warszawa.

WORLD Metal Statistics Yearbook, 1989–2020. World Bureau of Metal Statistics, United Kingdom.

WÓJCICKI A., KIERSNOWSKI H., DYRKA I., ADAMCZAK-BIAŁY T., BECKER A., GŁUSZYŃSKI A., JANAS M., KOZŁOWSKA A., KRZEMIŃSKI L., KUBERSKA M., PACZEŚNA J., PODHALAŃSKA T., ROMAN M., SKOWROŃSKI L., WAKSMUNDZKA M.I., 2014 – Prognostyczne zasoby gazu ziemnego w wybranych zwięzłych skałach zbiornikowych Polski [https://www.pgi.gov.pl/docman-tree-all/prasa/2995-raport-prognostyczne-zasoby-gazu-ziemnego-w-wybranych-zwiezlych-skalach-zbiornikowych-polski/file.html]. PIG-PIB, Warszawa.

WÓJCICKI A., DYRKA I., KIERSNOWSKI H., JANAS M., ADAMCZAK-BIAŁY T., BECKER A., GŁUSZYŃSKI A., KARCZ P., KOZŁOWSKA A., KUBERSKA M., PACZEŚNA J., PODHALAŃSKA T., ROMAN M., SKOWROŃSKI L., WAKSMUNDZKA M.I., 2017 (ed. 2018) – Prognostyczne zasoby gazu ziemnego i ropy naftowej w skałach łupkowych niższego paleozoiku w basenie bałtycko-podlasko-lubelskim (i strefie Biłgoraj-Narol). *In:* Szacowanie zasobów złóż węglowodorów – zadanie ciągłe PSG, I etap. Opracowanie końcowe (Wójcicki et al.). NGA, PGI-NRI, Warsaw. Narodowe Archiwum Geologiczne, Item No 9046/2019. PIG-PIB, Warszawa.

WÓJCICKI A. , KIERSNOWSKI H., PODHALAŃSKA T., JANAS M., GŁUSZYŃSKI A., PACZEŚNA J., ADAMCZAK-BIAŁY T., 2020 – Gaz i ropa z łupków (shale gas, shale oil), gaz zamknięty (tight gas). *In:* Bilans perspektywicznych zasobów kopalin Polski wg stanu na 31.12.2018 r. (eds. Szamałek K., Szuflicki M., Mizerski W.): 70–83. PIG-PIB, Warszawa.

ZUCHIEWICZ W., BADURA J., ALEKSANDROWSKI P., KASIŃSKI J.R., JAROSIŃSKI M., 2020 – Struktury kenozoiczne (młodoalpejskie). *In:* Atlas Geologiczny Polski (eds. Nawrocki J., Becker A.): 41. PIG-PIB, Warszawa.

ŻABA J., 2006 – Ilustrowana encyklopedia skał i minerałów. Wyd. Videograf II, Chorzów.

LEGAL ACTS

European Acts

Commission Regulation (EU) No 1006/2011 of 27 September 2011 amending Annex I to Council Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and on the Common Customs Tariff (Official Journal L 282, 28/10/2011).

Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability. COM (2020) 474 final.

Council Regulation (EC) No 254/2000 of 31 January 2000 amending Regulation (EEC) No 2658/87 on the tariff and statistical nomenclature and the Common Customs Tariff (Official Journal L 28, 3/02/2000).

Council Regulation (EEC) No 2658/87 of 23 July 197 on tariff and statistical nomenclature and on the Common Customs Tariff (Official Journal L 256, 07/09/1987).

International Convention on the Harmonized Commodity Description and Coding System (Official Journal No 11, pos. 62, 1997).

Regulation (EC) No 638/2004 of the European Parliament and of the Council of 31 March 2004 on Community statistics relating to the trading of goods between Member States and repealing Council Regulation (EEC) No 3330/91" (Official Journal L 102, 7/4/2004).

Polish Acts [English translation with original Polish version]

Act of 28th of July, 2005 on health resort treatment, health resort protection areas and health communities (Journal of Laws of 2005, Item 1399) [Ustawa z dnia 28 lipca 2005 r. o lecznictwie uzdrowiskowym, uzdrowiskach i obszarach ochrony uzdrowiskowej oraz gminach uzdrowiskowych (Dz.U. 2008, poz. 1399)].

Geological and Mining Law dated the 9th of June, 2011 (Journal of Laws of 2021, Item 1420, unified text) [Ustawa z 9 czerwca 2011 r. Prawo geologiczne i górnicze (Dz. U. z 2021 r., poz. 1420, tekst ujednolicony)].

Regulation by the Minister of the Environment amending regulation on the classification of mineral reserves and resources (dated the 9th of January, 2007 – Journal of Laws of 2007, Item 57) [Rozporządzenie Ministra Środowiska z dnia 9 stycznia 2007 r. zmieniające rozporządzenie w sprawie kryteriów bilansowości złóż kopalin (Dz.U. 2007, poz. 57)].

Regulation by the Minister of the Environment on the paid use of geological information (dated the 20th of December, 2011 – Journal of Laws of 2011, Item 1724) [Rozporządzenie Ministra Środowiska z dnia 20 grudnia 2011 r. w sprawie korzystania z informacji geologicznej za wynagrodzeniem (Dz.U. 2011, poz. 1724)].

Regulation by the Minister of the Environment on detailed requirements of a mineral deposit development plans (dated the 24th of April, 2012 – Journal of Laws of 2012, Item 511) [Rozporządzenie Ministra Środowiska z dnia 24 kwietnia 2012 r. w sprawie szczegółowych wymagań dotyczących projektów zagospodarowania złóż (Dz.U. 2012, poz. 511)].

Regulation by the Minister of the Environment on a geological documentation of a raw material deposit excluding hydrocarbons (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 987) [Rozporządzenie Ministra Środowiska z dnia 1 lipca 2015 r. w sprawie dokumentacji geologicznej złoża kopaliny, z wyłączeniem złoża węglowodorów (Dz.U. 2015, poz. 987)].

Regulation by the Minister of the Environment on a geological-investment documentation of a hydrocarbons field (dated the 1st of July, 2015 – Journal of Laws of 2015, Item 968) [Rozporządzenie Ministra Środowiska z dnia 1 lipca 2015 r. w sprawie dokumentacji geologiczno-inwestycyjnej złoża węglowodorów (Dz.U. 2015, poz. 968)].

Regulation by the Minister of Health on the scope of studies necessary to establish therapeutical features of natural therapeutical raw materials and the therapeutical feature of climate, criteria for their assessment and the certificate template confirming such features (dated the 13th of April, 2006 – Journal of Laws of 2006, Item 565) [Rozporządzenie Ministra Zdrowia z dnia 13 kwietnia 2006 r. w sprawie zakresu badań niezbędnych do ustalenia właściwości leczniczych naturalnych surowców leczniczych i właściwości leczniczych klimatu, kryteriów ich oceny oraz wzoru świadectwa potwierdzającego te właściwości (Dz.U. 2006, poz. 565)].

WEBSITES

Generalna Dyrekcja Dróg Krajowych i Autostrad (GDDKiA), 2021 – https://www.gov.pl/web/gddkia/mapa-stanu-budowy-drog3.

The balance of mineral resources deposits in Poland archives – https://www.pgi.gov.pl/bilans-zasobow.

The Central Geological Database – http://baza.pgi.gov.pl.

The Central Geological Database Download Manager – http://dm.pgi.gov.pl.

The Central Geological Database, database HAŁDY – https://cbdgportal.pgi.gov.pl/haldy.

Generalny Dyrektor Ochrony Środowiska, 2021 – https://www.gov.pl/attachment/f105bae3-affc-4c65-a830-0f178ca345dd.

The Mineral Groundwater Data Bank – http://spd.pgi.gov.pl/PSHv8.

The GeoLOG mobile application – https://geolog.pgi.gov.pl.

The InfoGeoSkarb system – http://geoportal.pgi.gov.pl/igs.

The Geology mapping portal – https://geologia.pgi.gov.pl.

The Mineral resources of Poland website – http://surowce.pgi.gov.pl.

The Minister of Health – https://www.gov.pl/web/zdrowie.

The Polish Geological Institute – National Research Institute Databases – https://www.pgi.gov.pl/en/data-bases.html.

The Polish Hydrogeological Survey (PHS) – www.psh.gov.pl.

The System of management and protection of mineral resources in Poland – MIDAS – http://www.midas.pgi.gov.pl; http://geoportal.pgi.gov.pl/midas-web.

The System of management and protection of mineral resources in Poland – MIDAS; the module Economy of raw materials – http://geoportal.pgi.gov.pl/midas-web/pages/index.jsf?conversationContext=1.

The System of management and protection of mineral resources in Poland – MIDAS; Spatial data – http://geoportal.pgi.gov.pl/portal/page/portal/midas/dane_przestrzenne.

The ZE PAK S.A., 2021 – https://ri.zepak.com.pl/pl/aktualnosci/1469-zielone-kierunki-strategii-ze-pak-sa-zaakceptowane-koniec-z-energia-z-wegla-najpozniej-w-2030-roku.html.

USEFUL LINKS

The National Fund for Environmental Protection and Water Management (NFEP&WM) – www.nfosigw.gov.pl/en.

Ministry of Climate and Environment – https://www.mos.gov.pl/en.

The State Mining Authority – http://www.wug.gov.pl/english.

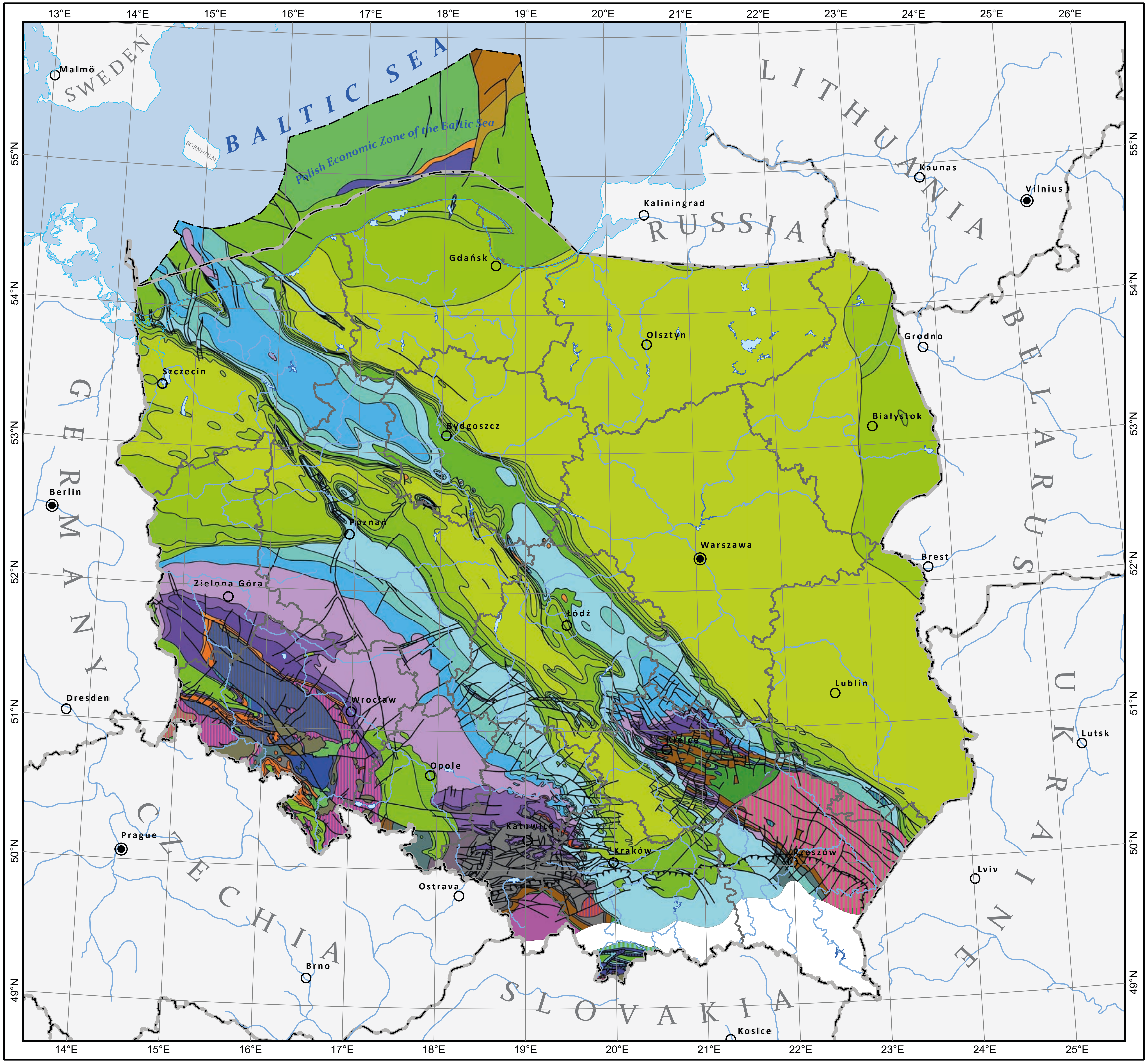
The General Directorate for Environmental Protection – https://www.gdos.gov.pl/eng.

Polish Geological Institute – National Research Institute – http://www.pgi.gov.pl/en.

Plate 1

GEOLOGICAL MAP OF POLAND WITHOUT CENOZOIC DEPOSITS

(after Pieńkowski and Kramarska, 2017)



0 50 100 km

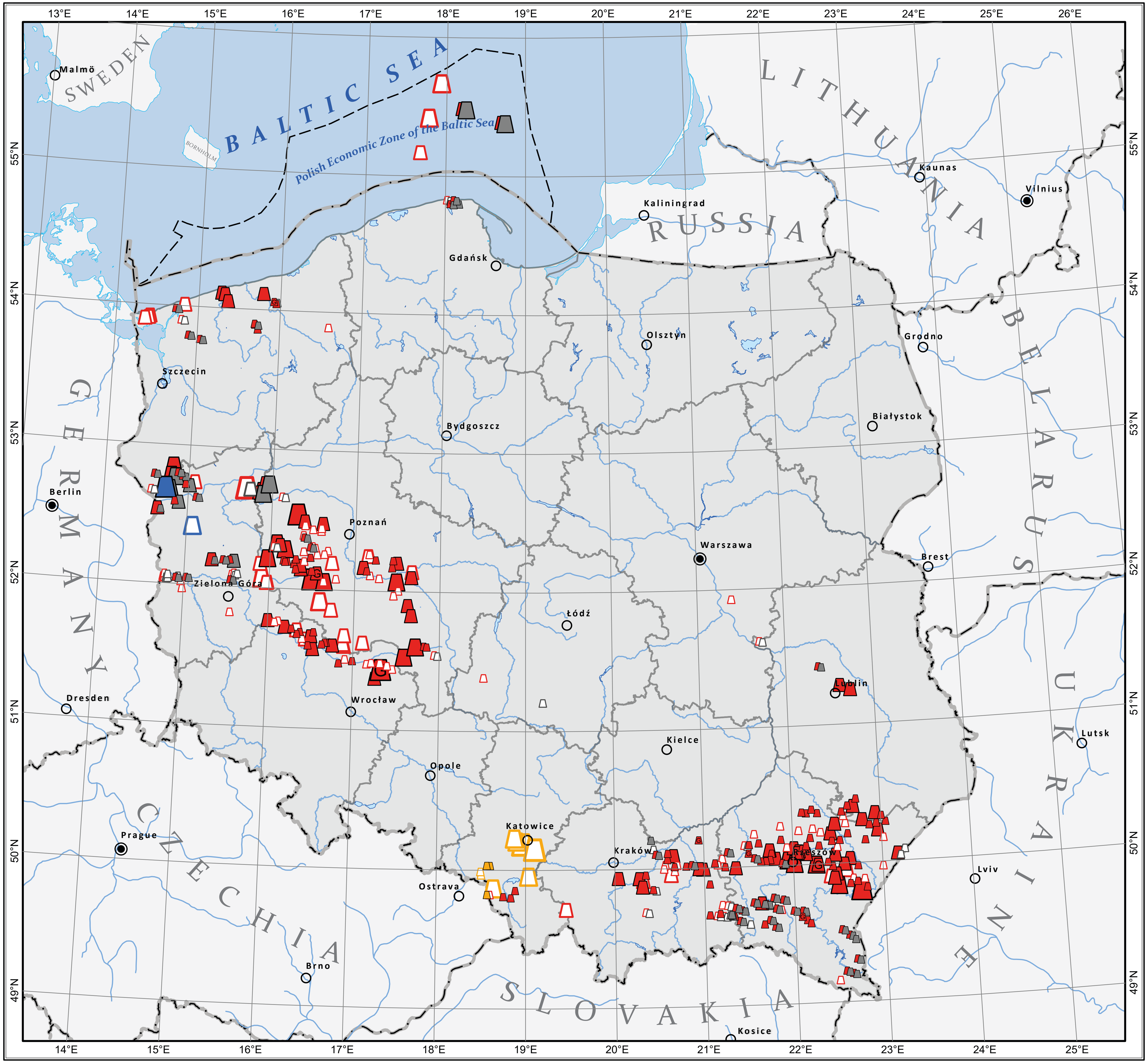
Legend:

- Maastrichtian
- Campanian
- Coniacian + Santonian
- Turonian
- Cenomanian + Turonian
- Upper Cretaceous
- Upper Albian-Turonian
- Upper Albian + Cenomanian
- Lower Cretaceous
- Cretaceous
- Jurassic-Cretaceous
- Upper Jurassic
- Middle Jurassic
- Lower Jurassic
- Jurassic
- Keuper (~Upper Triassic)
- Muschelkalk (~Middle Triassic)
- Buntsandstein (~Lower-Middle Triassic)
- Triassic
- Zechstein (~Upper Permian)
- Rotliegend (~Lower + Middle Permian)
- Permian
- Permian + Triassic
- Upper Carboniferous (Serpukhovian-Gzhelian)
- Upper Carboniferous (Serpukhovian-Gzhelian) - granitoids
- Visean + Namurian (Serpukhovian + Bashkirian)
- Lower Carboniferous (Tournaisian + Visean)
- Carboniferous
- Upper Devonian + Lower Carboniferous (Tournaisian + Visean)
- Upper Devonian
- Middle Devonian
- Lower + Middle Devonian
- Lower Devonian
- Devonian
- Silurian-Lower Carboniferous (Tournaisian + Visean)
- Silurian
- Ordovician-Lower Carboniferous (Tournaisian + Visean) - metamorphosed rocks
- Ordovician + Silurian - metamorphosed rocks
- Ordovician
- Ordovician - metamorphosed granitoids
- Cambrian-Silurian
- Cambrian
- Ediacaran + Cambrian
- Neoproterozoic-Carboniferous
- Neoproterozoic-Ordovician - metamorphosed rocks
- Neoproterozoic + Lower Cambrian (~Terreneuvian + Series 2) - granitoids
- Neoproterozoic
- Precambrian (Archean + Proterozoic) - igneous rocks and various-grade metamorphic rocks
- Carpathian overthrust front
- Overthrust
- Fault
- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk

Polish Geological Institute - National Research Institute

Plate 2



OIL AND GAS FIELDS

0 50 100 km

Exploitable anticipated economic resources:
(after Szuflicki et al., eds., 2021)

Fields in exploitation	Not exploited fields	
0.2 1 Mt	0.2 1 Mt	Crude oil
0.2 1 5 bnm^3	0.2 1 5 bnm^3	Natural gas
0.2 1 5 bnm^3		Underground gas storage
0.2 1 5 bnm^3	0.2 1 5 bnm^3	Coal-bed methane (CBM) as the main raw material in a deposit
1 5 bnm^3	1 5 bnm^3	High nitrogen natural gas

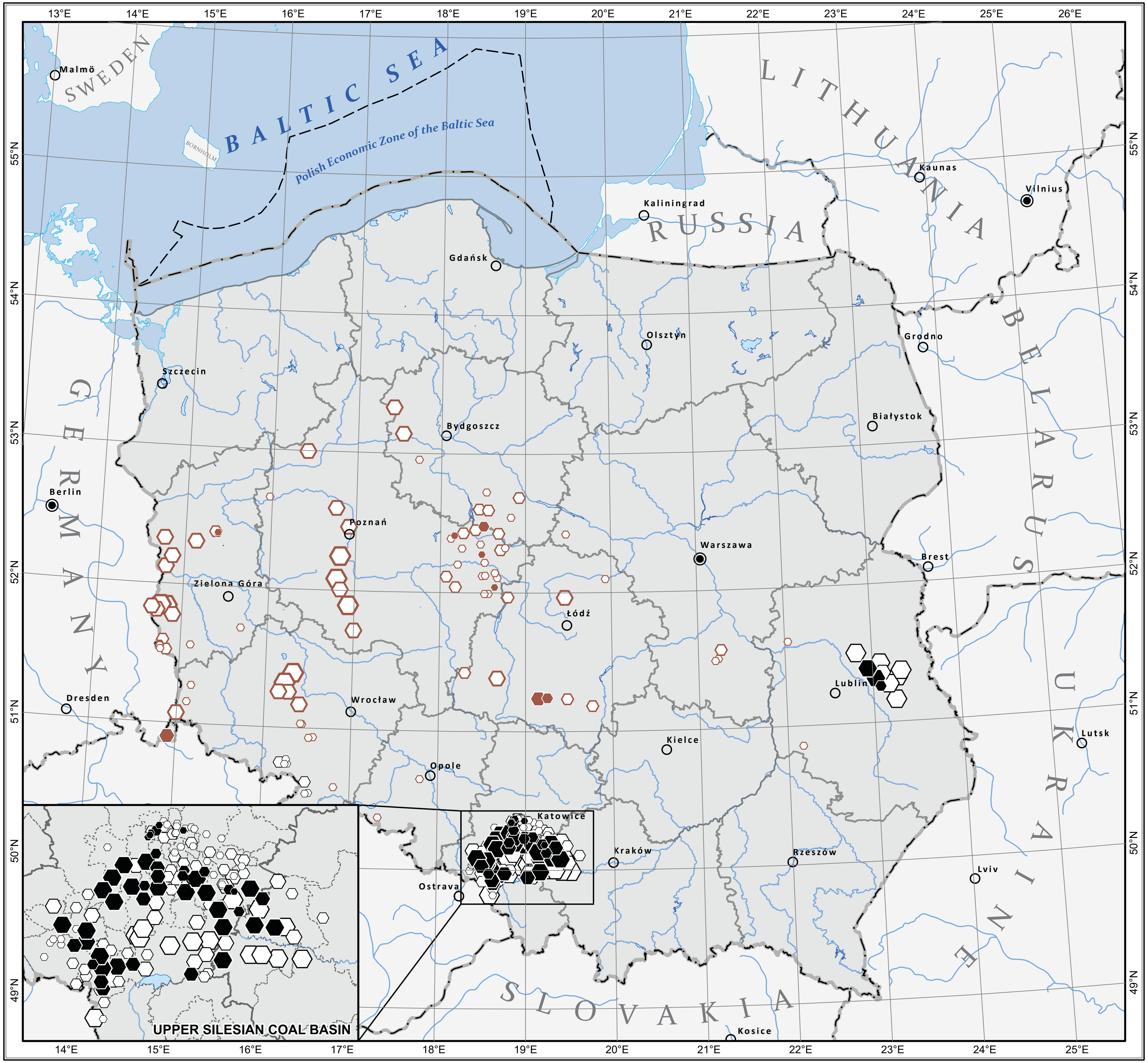
Other legends symbols:

- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Plate 3

HARD COAL AND LIGNITE DEPOSITS



0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Deposits in exploitation	Not exploited deposits	
50 200 500 Mt	50 200 500 Mt	Hard coal
20 200 1000 Mt	20 200 1000 Mt	Lignite

Other legends symbols:

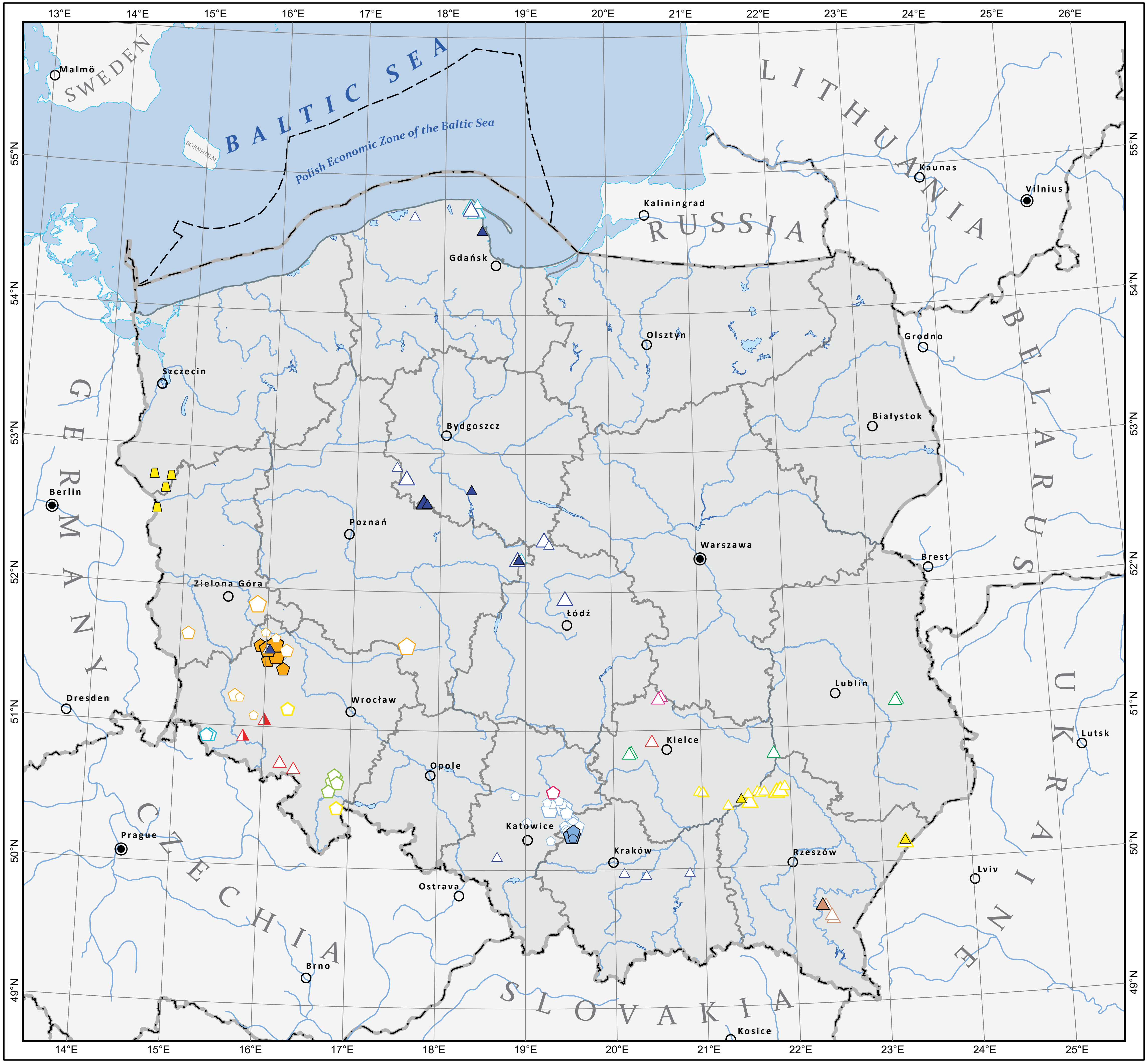
- State boundaries
- Voivodeship boundaries
- County boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

Plate 4

METALLIC AND CHEMICAL RAW MATERIALS DEPOSITS



0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Metallic raw materials:

Deposits in exploitation	Not exploited deposits	
0.5 5 Mt	0.5 5 Mt	Copper and silver ores
0.1 0.5 Mt	0.1 0.5 Mt	Zinc and lead ores
		Molybdenum-tungsten-copper ores
		Nickel ores
		Tin ores
		Arsenic and gold ores

Chemical raw materials:

Deposits in exploitation	Not exploited deposits	
50 Mt	50 Mt	Native sulfur
		Sulfur as a by-product (in natural gas fields)
5000 Mt	5000 Mt	Rock salt
	100 Mt	Potassium-magnesium salt
		Diatomite rock
		Barite
		Barite and fluorspar
		Siliceous earth
		Clay raw materials used in the production of mineral paints

Other legends symbols:

- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

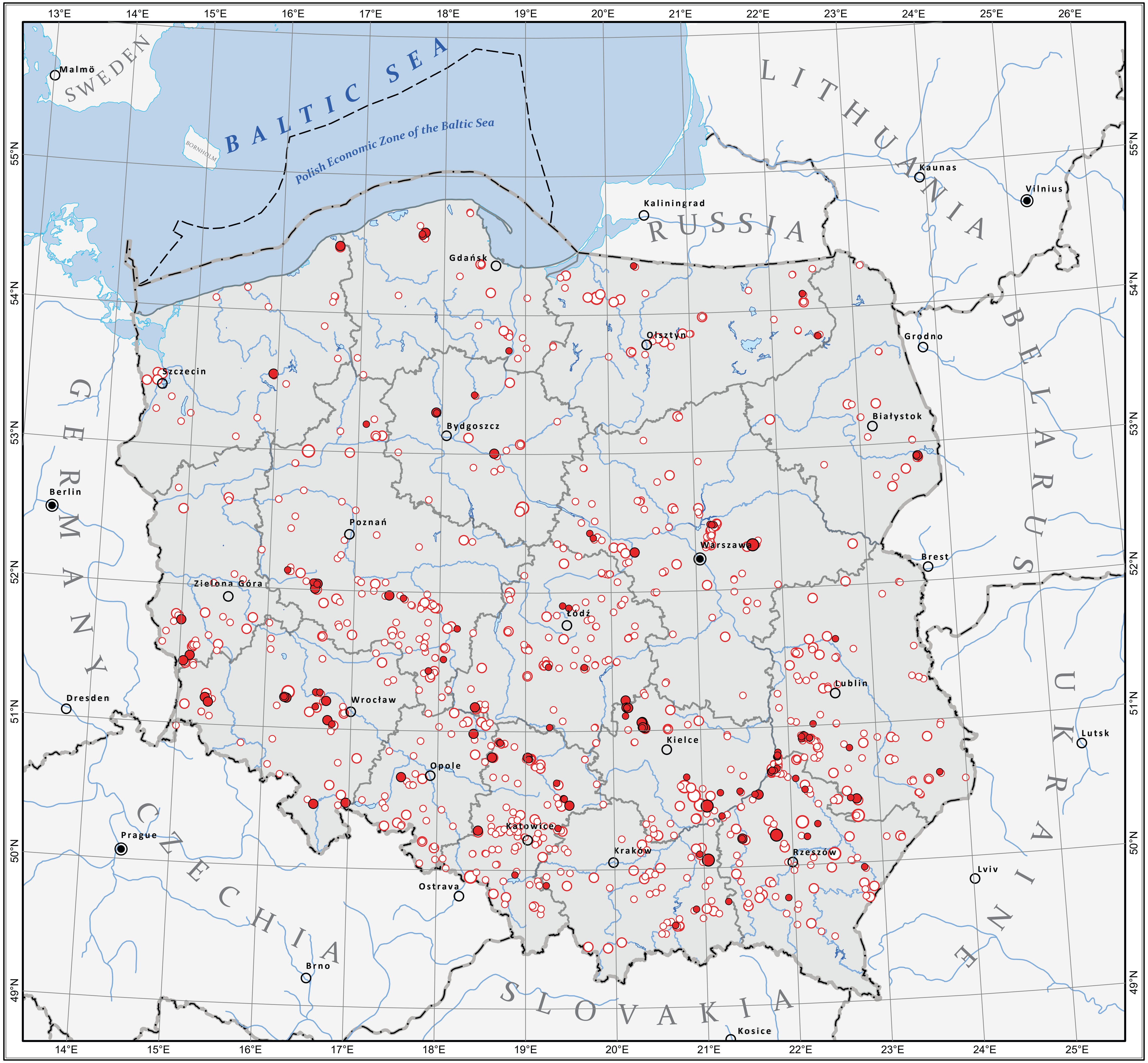


Plate 5

BUILDING CERAMICS RAW MATERIALS DEPOSITS

0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Deposits in exploitation — 1, 10 Mm³

Not exploited deposits — 1, 10 Mm³

Building ceramics

Other legends symbols:

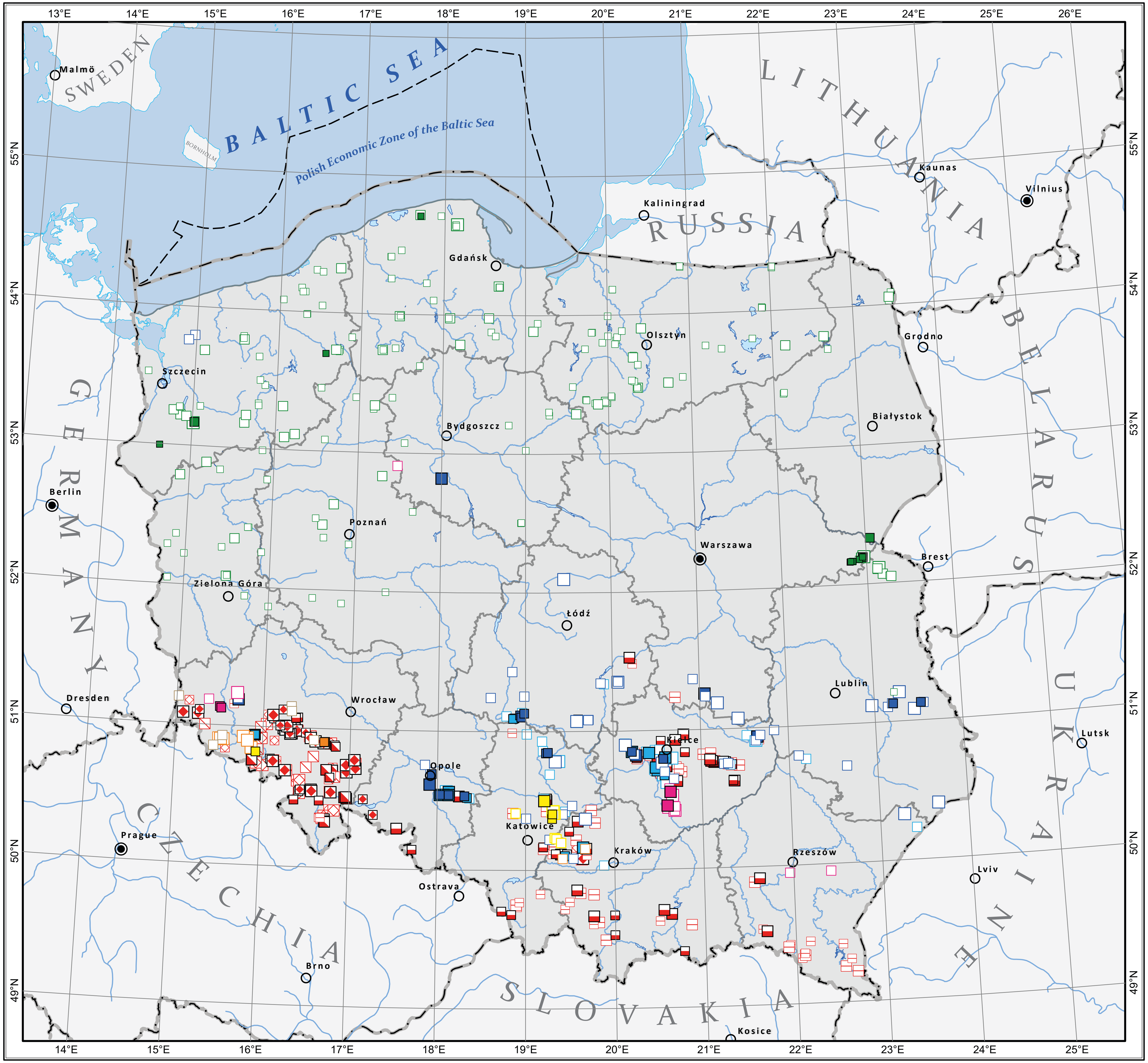
- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

Plate 6

ROCK RAW MATERIALS DEPOSITS



0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Deposits in exploitation | Not exploited deposits

- 50 Mt — Dolomite
- 20 Mt — Gypsum and anhydrite
- 1 10 Mt — Chalk
- 10 Mt — Feldspar raw materials
- 10 200 Mt — Limestone and marl for the cement industry
- 10 100 Mt — Limestone for the lime industry
- Vein quartz

Dimension and crushed stone:

Deposits in exploitation | Not exploited deposits

- 10 25 Mt — Sedimentary rocks
- 10 25 Mt — Metamorphic rocks
- 10 25 Mt — Igneous rocks

Other legends symbols:

- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

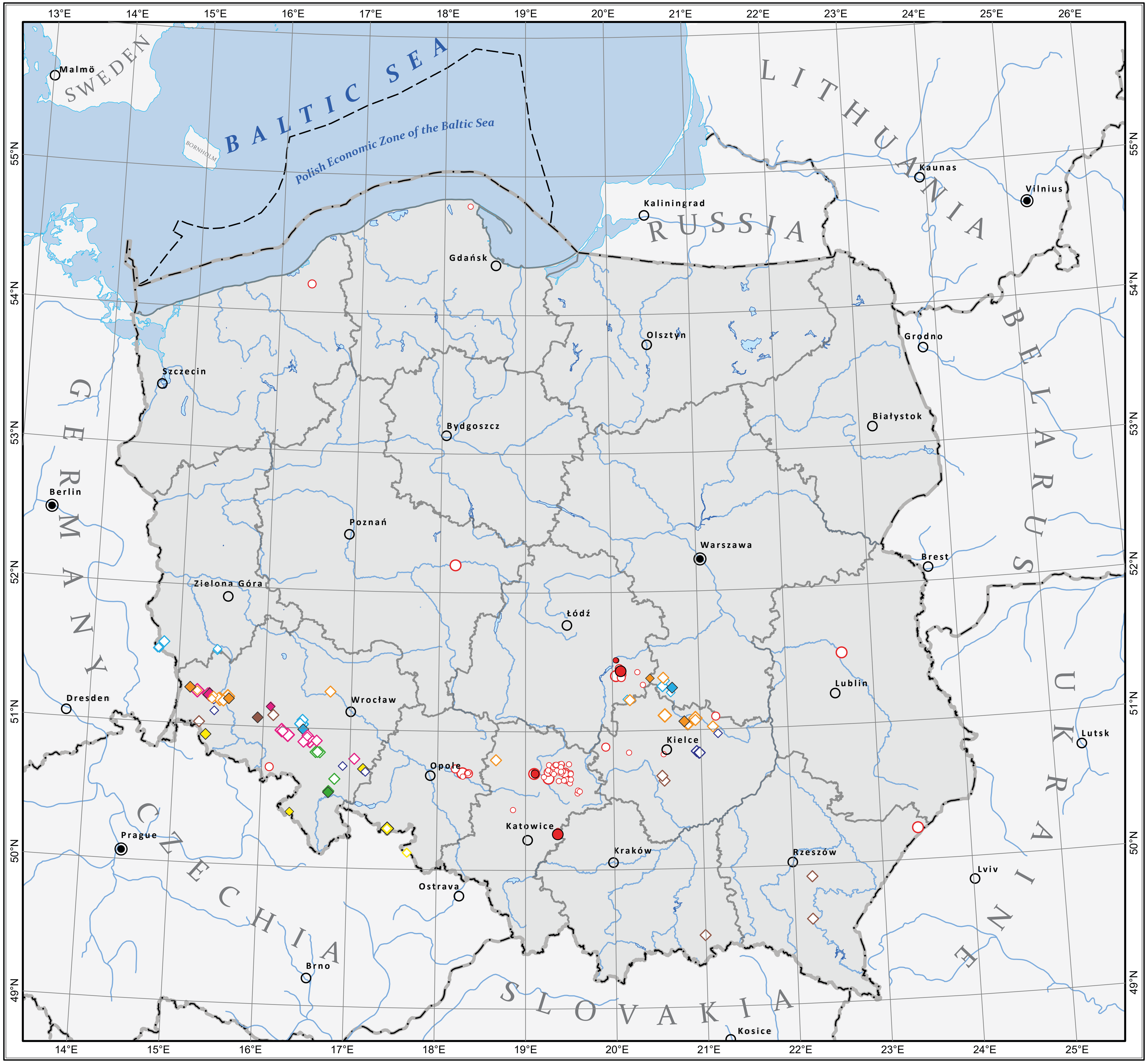


Plate 7

CERAMIC AND REFRACTORY RAW MATERIALS DEPOSITS

0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Deposits in exploitation	Not exploited deposits	
		Bentonite and bentonitic clays
1 10 Mt	1 10 Mt	Ceramic clays
1 10 Mt	1 10 Mt	Foundry sand
1 10 Mt	1 10 Mt	Kaolin
		Magnesite
1 10 Mt	1 10 Mt	Refractory clays
	1 Mt	Refractory quartzite
5 10 Mt	5 10 Mt	Phyllite, quartzitic and micaceous schist

Other legends symbols:

- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

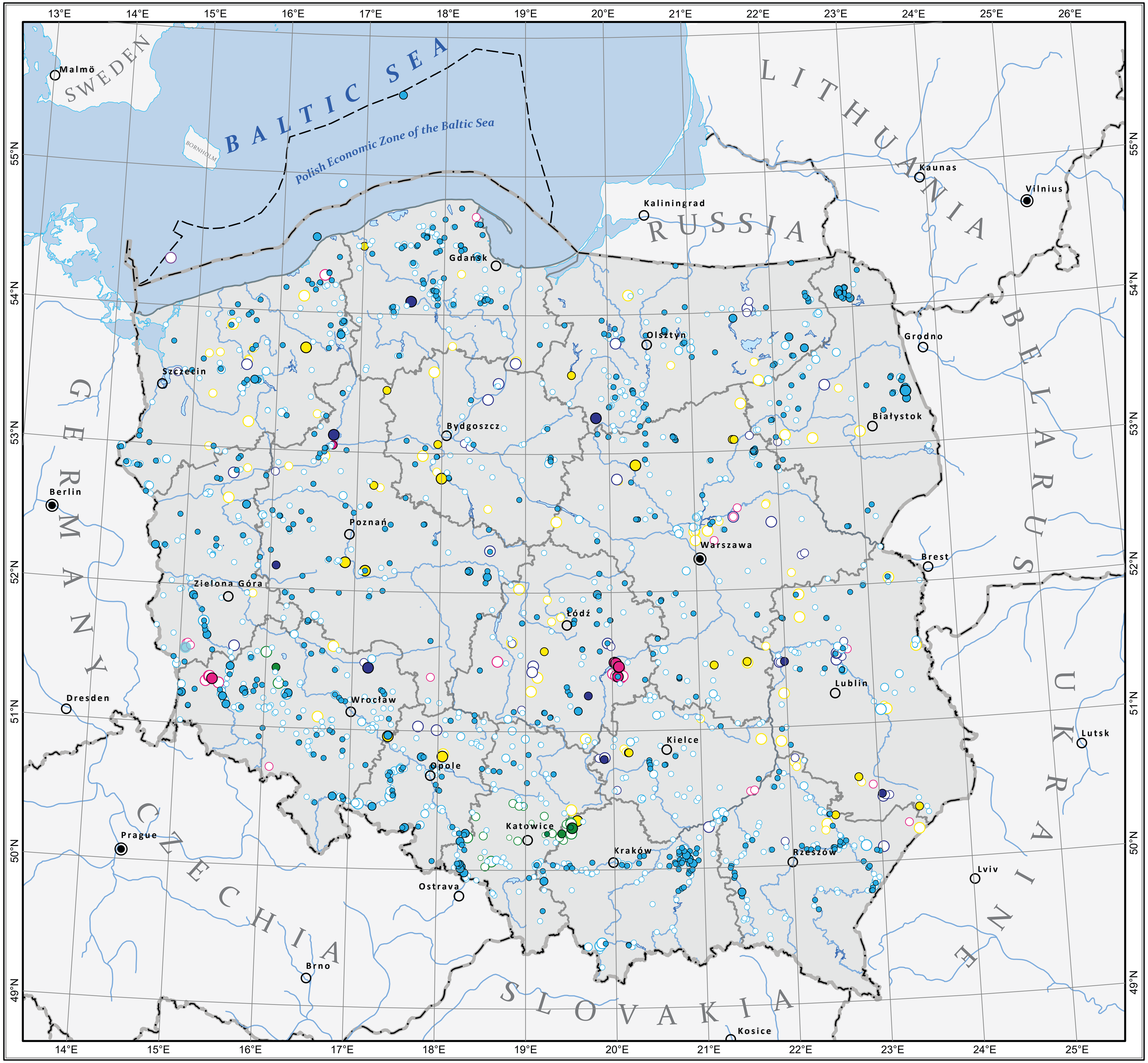


Plate 8

CLASTIC ROCK RAW MATERIALS DEPOSITS

0 50 100 km

Anticipated economic resources *(after Szuflicki et al., eds., 2021)*:

Deposits in exploitation	Not exploited deposits	
2 20 100 Mt	2 20 100 Mt	Sand and gravel
10 Mt	10 Mt	Glass sand and glass sandstone
10 100 Mm³	10 100 Mm³	Filling sand
2 Mt	2 Mt	Quartz sand for production of cellular concrete
2 Mt	2 Mt	Quartz sand for production of sand-lime brick
		Sand with heavy minerals

Other legends symbols:

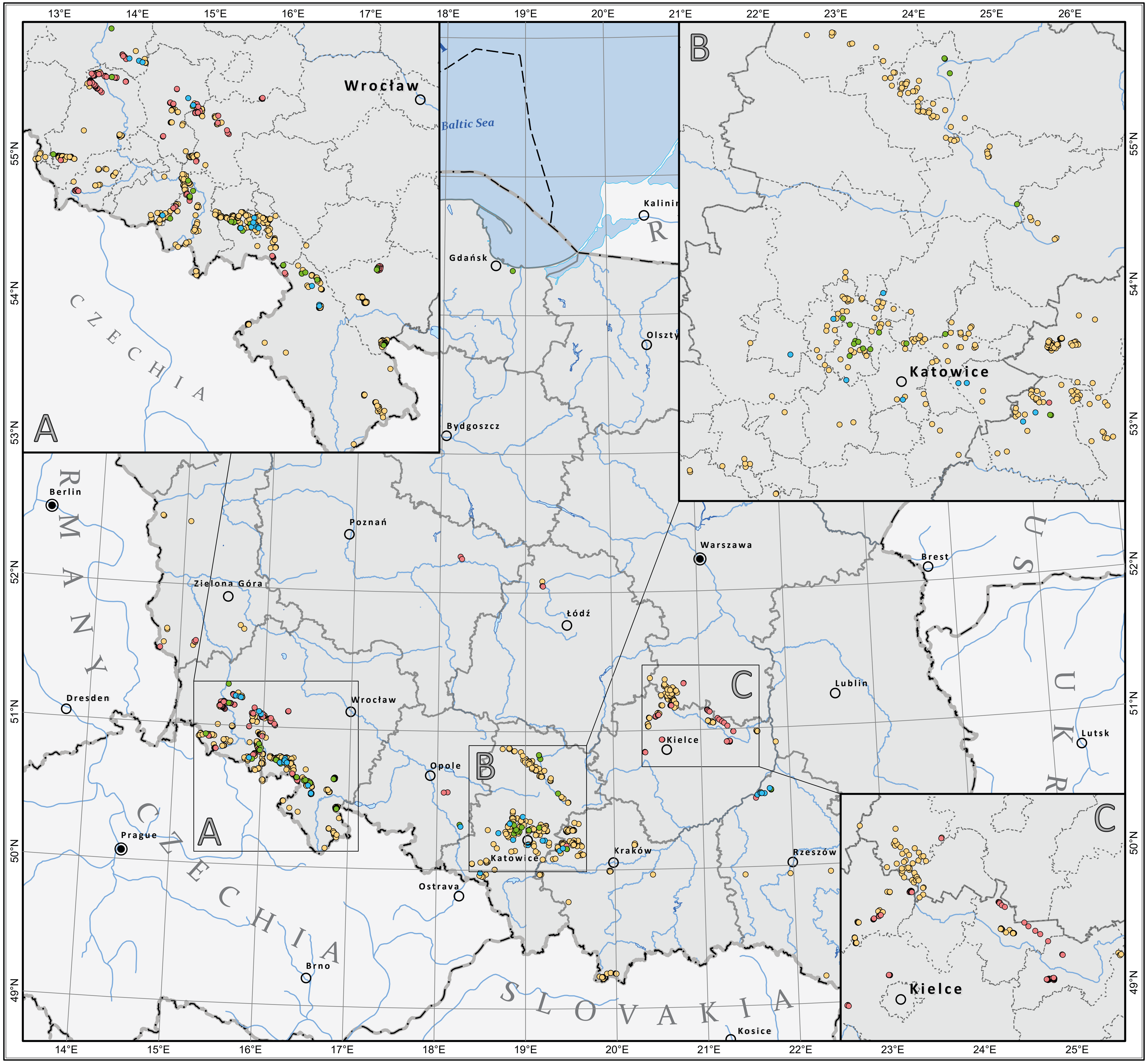
- State boundaries
- Voivodeship boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk, R. Bońda, D. Siekiera

Polish Geological Institute - National Research Institute

Plate 9

LOCATION OF OLD MINING AND INDUSTRY OBJECTS IN POLAND



0 50 100 km

Extractive wastes *(cbdgportal.pgi.gov.pl/hałdy)*:

- Industrial settling pond
- Industrial waste storage site
- External waste dump
- Mining waste dump

Other legends symbols:

- State boundaries
- Voivodeship boundaries
- County boundaries
- Polish Economic Zone of the Baltic Sea
- Rivers
- Reservoirs

Graphic and technical computer elaboration:
M. Woroszkiewicz, J. Fabiańczyk

Polish Geological Institute - National Research Institute