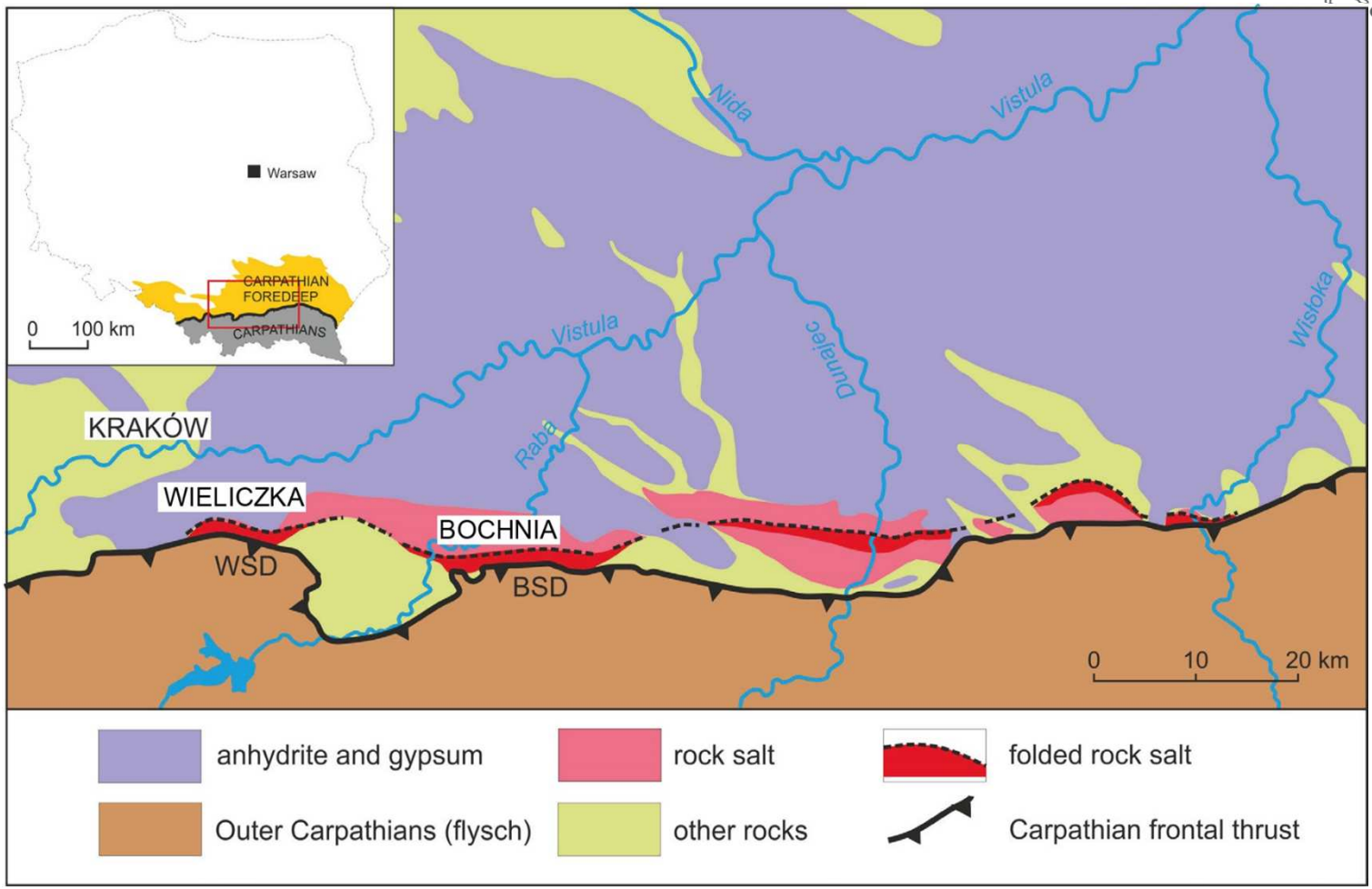
Jerzy Przybyło and Michał Źróbek

SALT MINE „WIELICZKA” - the history of mining and geology

Wieliczka Salt Mine - graphics from the 19th century
(1840 - raport *Commission Scientifique du Nord*)

WIELICZKA SALT DEPOSIT

Salt deposits in the the Polish Carpathian Foredeep

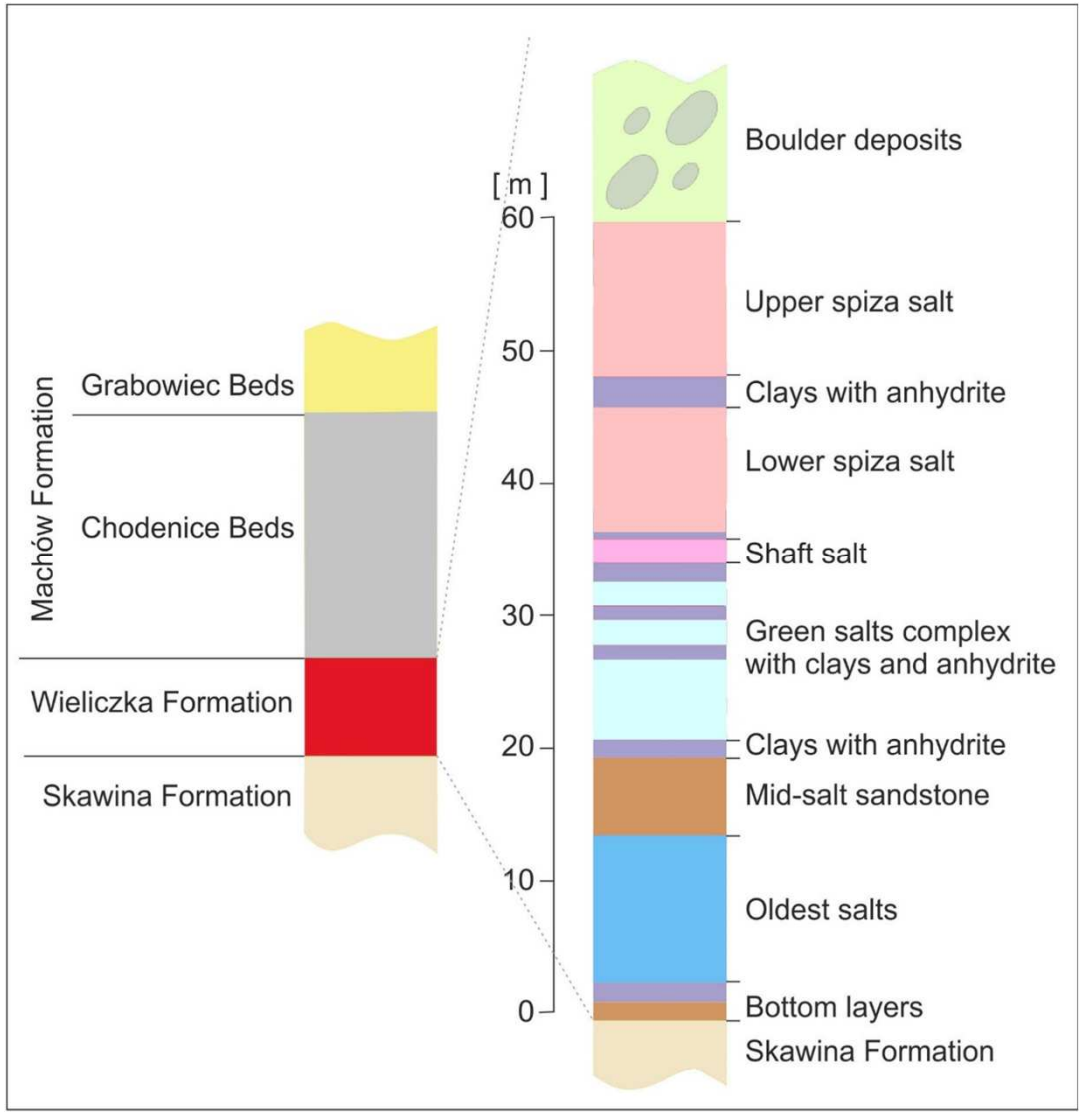


Wieliczka salt deposit was formed in the pre-mountainous basin called the Carpathian Foredeep

Salt deposits in the the Carpathian Foredeep are located along the shore of the Carpathian Mountains

WIELICZKA SALT DEPOSIT

Litostratigraphy of the Wieliczka deposit



The deposit was formed in the Miocene (baden) between 13.8 and 13.6 million years ago.

It is a sodium chloride salt deposit, potassium and magnesium chlorides do not existe.

Wieliczka salts deposit characterized high lithological variability.

Its final form was given by tectonic movements of the Carpathians in Alpine orogeny.

The deposit shows high tectonic deformation.

The boulder deposit dominates the higher levels of the mine. Green salt lumps have been exploited in the most impressive chambers.

Salt layers of the stratiform deposit are contaminated by terrigenous material to varying degrees .

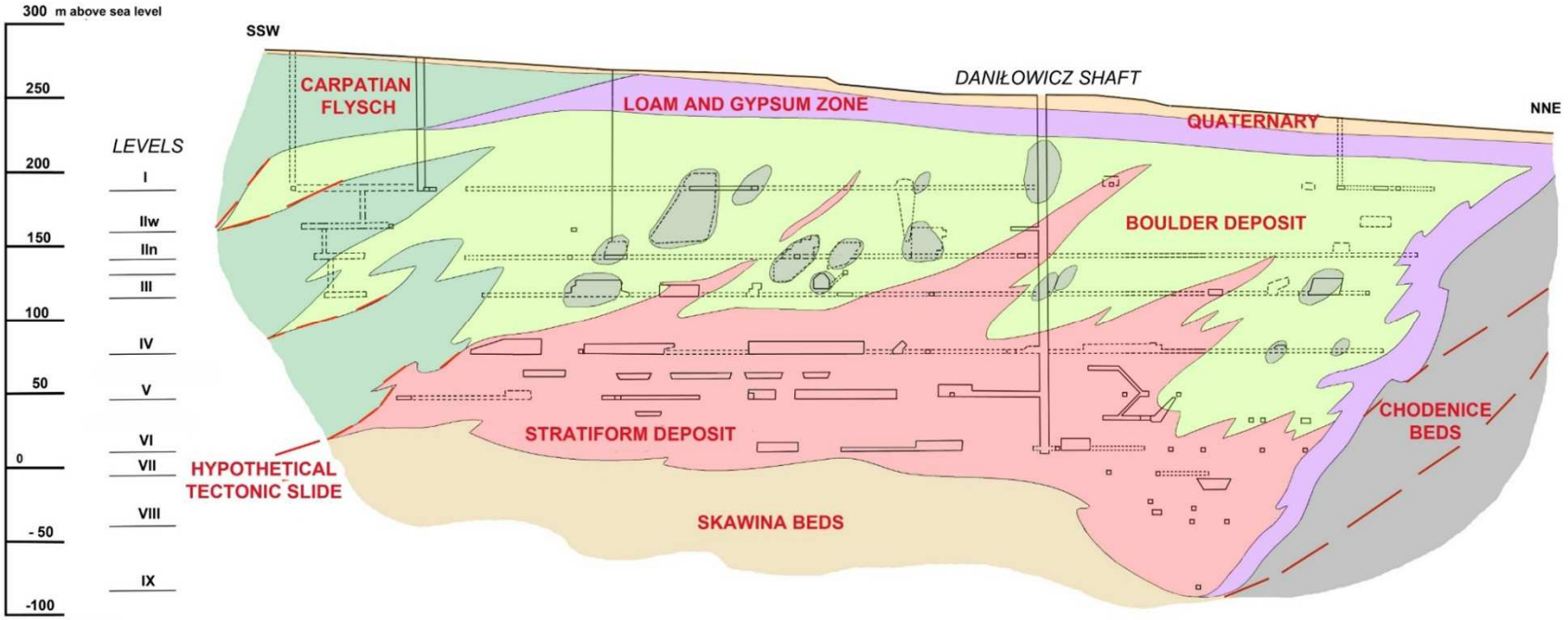
The most pure species of salt is the shaft salt layer.

The more contaminated sort of salt salt layers were mined after World War II using the wet method.

Underground exploitation of the deposit began in the second half of the 13th century, it was completed (finished) in 1996.

WIELICZKA SALT DEPOSIT

Simplified geological cross-section through the Wieliczka deposit



The entire salt deposit lies from about 30 m below the ground surface to about 340 m below the ground surface

The extension of the deposit (W-E direction), it is about 10 km long, and its width ranges (N-S direction) from about a few hundred meters to about 1.5 km

A characteristic feature of the deposit is duality of geology structures. It consists of the boulder deposit (upper part) and the stratiform deposit (lower part).

The boulder deposit consists of blocks of rock salt called green salt distributed in clay-salt rocks called zuber.

The stratiform (layered) deposit consists of layers of salt preceded (separated) by claystone and siltstone with anhydrite

The boulder deposit is unique among the world's salt deposits

WIELICZKA SALT DEPOSIT

Examples of the boulder deposit

The boulder deposit consists of blocks of rock green salt located in clay-salt rocks called zuber

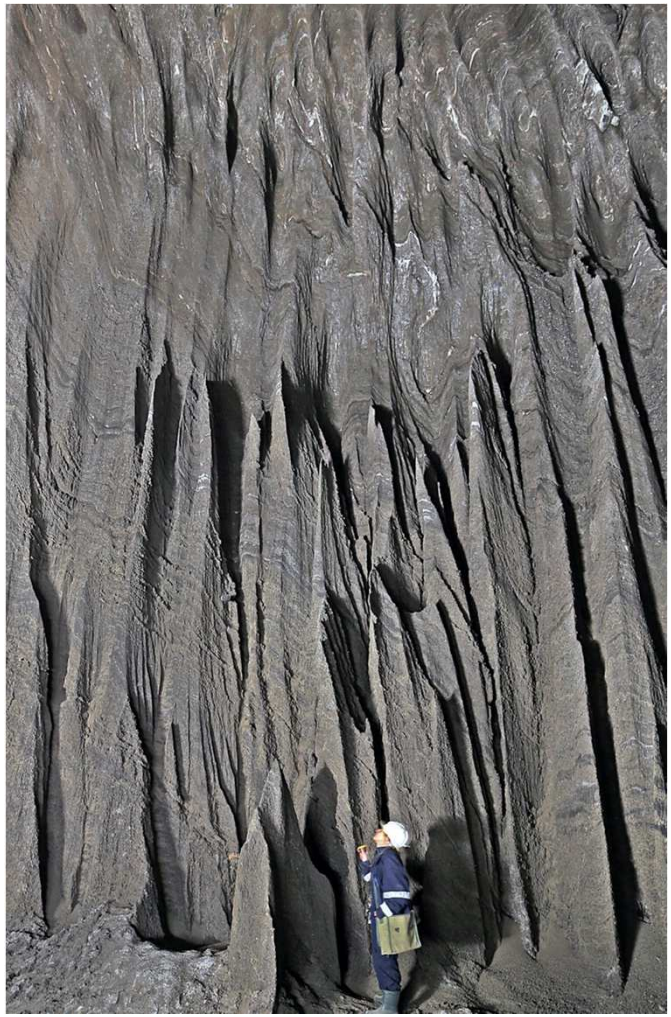
These are disintegrated fragments of salt layers as a result of tectonic or sedimentary processes

The origin of the boulder deposit is not clear

The salt blocks are of various sizes and are distributed differently in the zubers

WIELICZKA SALT DEPOSIT

Example of a chamber from the boulder deposit



Usually chambers excavated in salt blocks are high, but in horizontal direction they are not wide

WIELICZKA SALT DEPOSIT

Examples of the stratiform deposit

The stratiform (layered) deposit is characterized by lithological diversity and interesting tectonics

Spiza salt fold

WIELICZKA SALT DEPOSIT

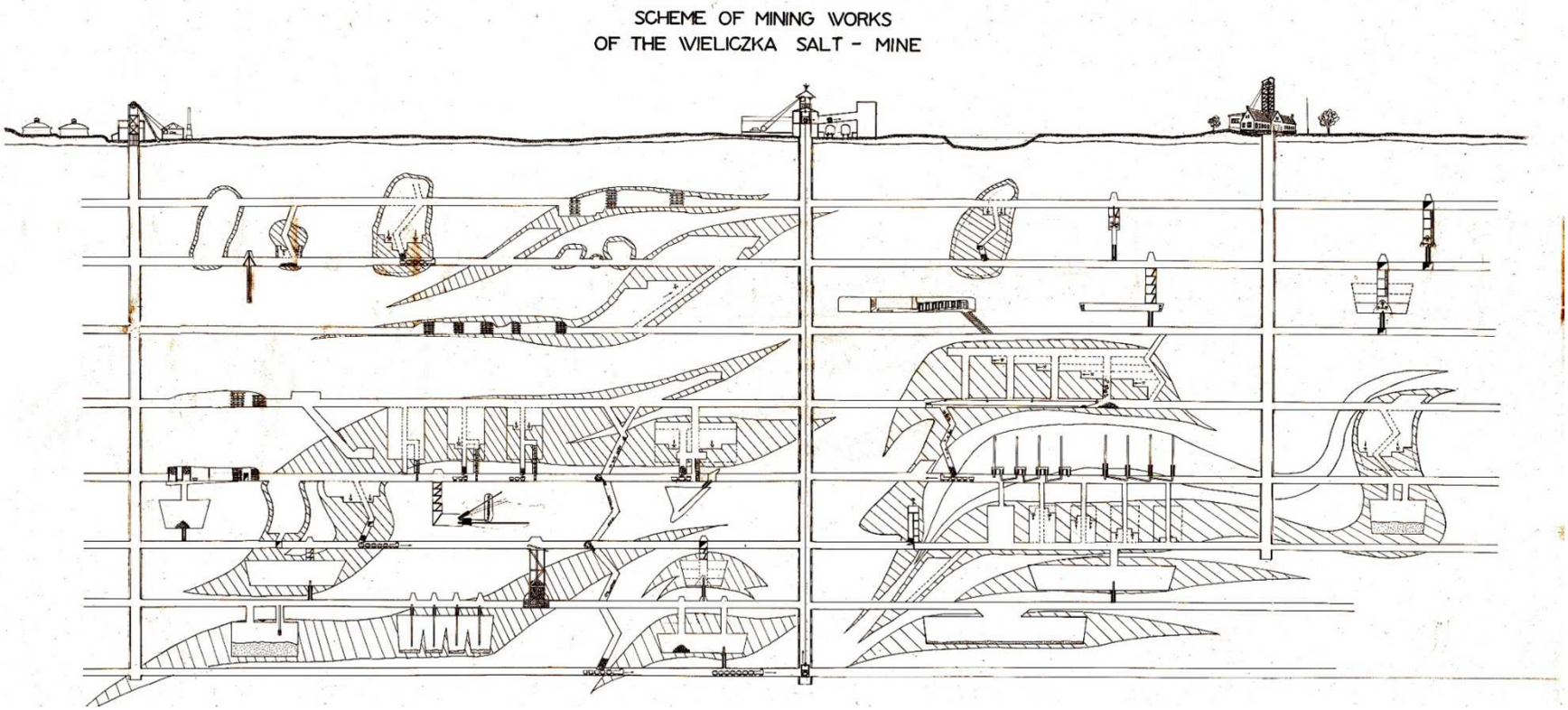
Examples of a chambers from the stratiform deposit

Excavations from the 19th century

The chambers used to exploit the stratiform (layered) deposit are generally low and wide

WIELICZKA SALT MINE

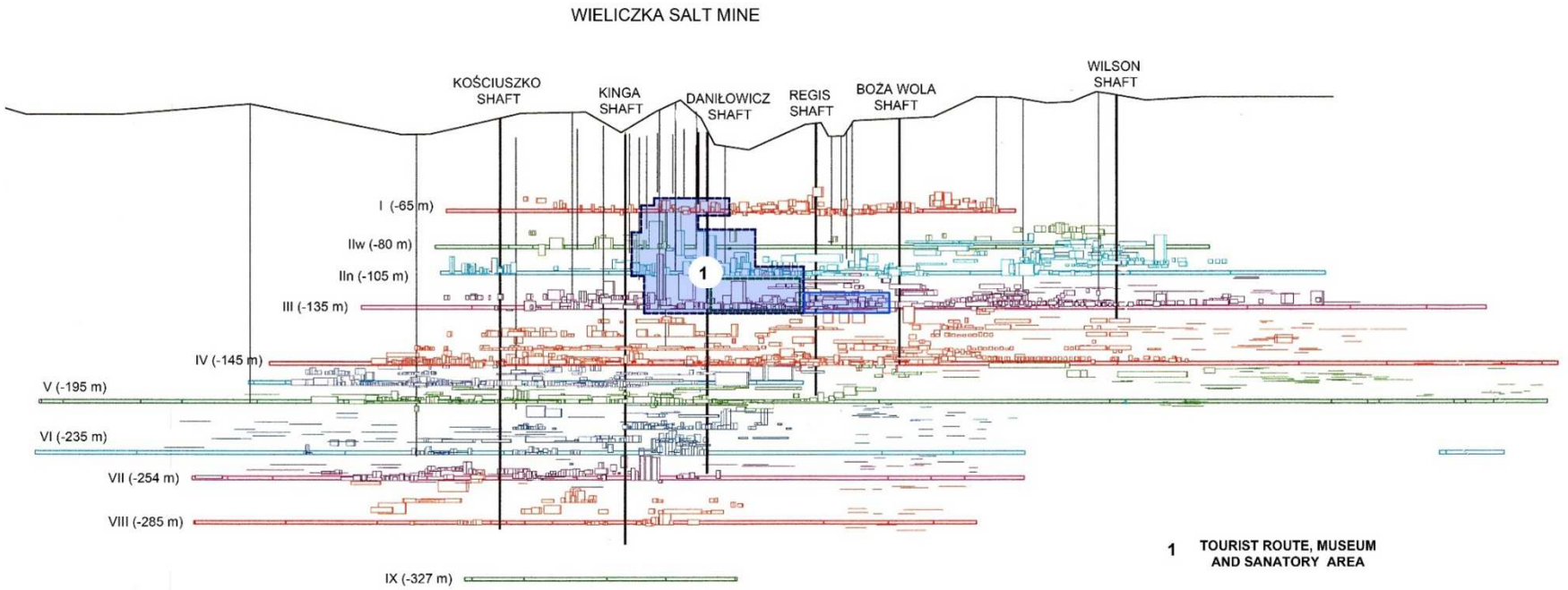
Mining works over the centuries



The deposit has been hollow out by various methods throgh the centuries - initially "dry", then in the 20th century "wet" (leaching). The boulder and the stratiform deposits were also exploited differently

WIELICZKA SALT MINE

Levels of the mine



Nowdays there are ten levels in the mine from I to IX (two levels II - higher and lower)

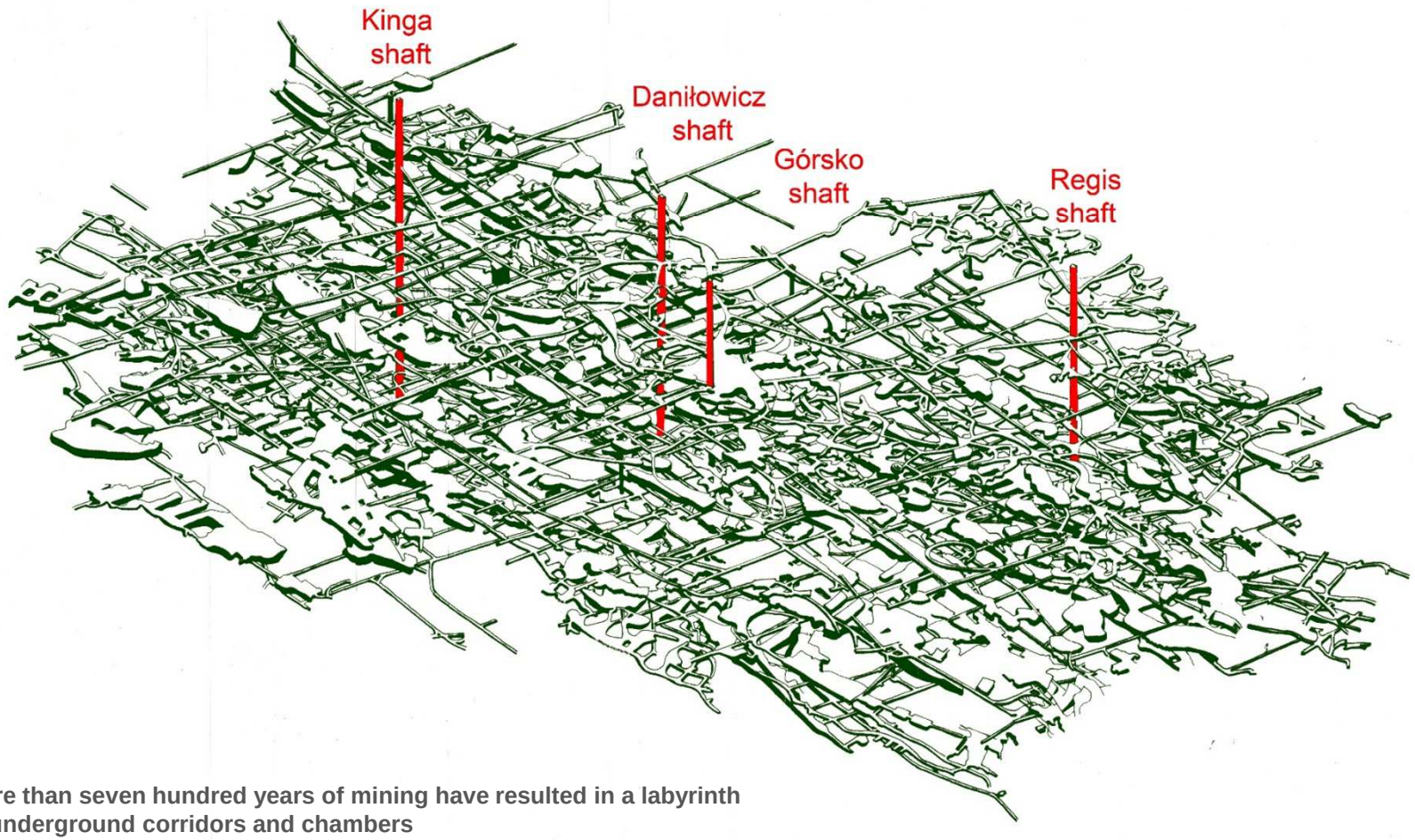
Level I is at a depth of about 65 m underground, level IX about 327 m underground

About 250 kilometers of corridors and more than 2,500 chambers have been inventoried

The tourist, museum and sanatorium part occupies only about a dozen percent of the total mine

WIELICZKA SALT MINE

Spatial arrangement of excavations – central part of the mine



More than seven hundred years of mining have resulted in a labyrinth of underground corridors and chambers

One of the reasons for the UNESCO World Heritage List listing was the complex layout of the mine workings

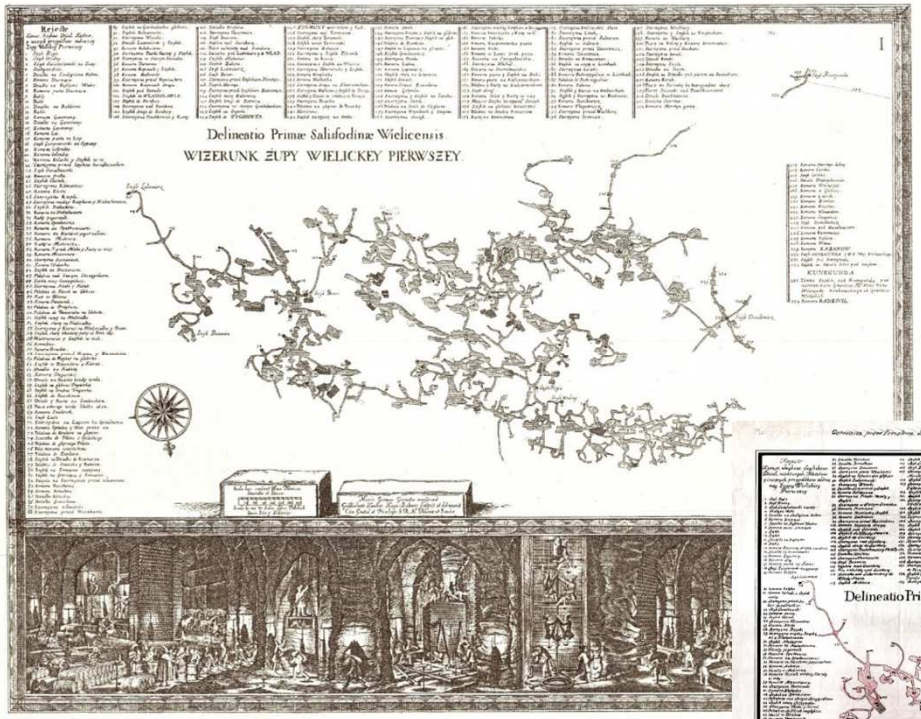
WIELICZKA SALT MINE

The mine in the 14th and 15th centuries

Kazimierz III Wielki (Casimir III The Great) (1310-1370) in 1368 legislate The Salt Works Statute – it was the firtst written law replaceing the existing customery law (habit law)

WIELICZKA SALT MINE

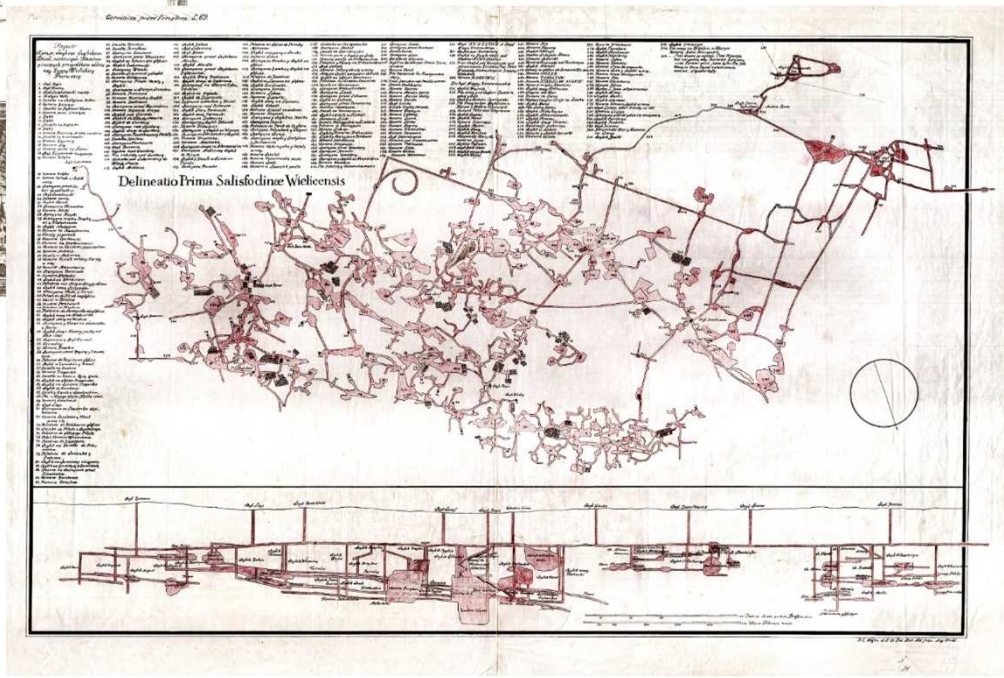
The mine in the 17th and 18th centuries



Map of I Level of Mine by German

The first known geometry mesurments was made by Jan Brożek- mathematician of Jagiellonian University

The first maps of the mine was made by geometer Martin German, published in 1645



Map of the first level of the mine, which is an update of the German map made by J. G. Borlach from 1718 – 1727 (published J. E. Nilson)

WIELICZKA SALT MINE

The mine phenomenon has fascinated scholars in XVIII century

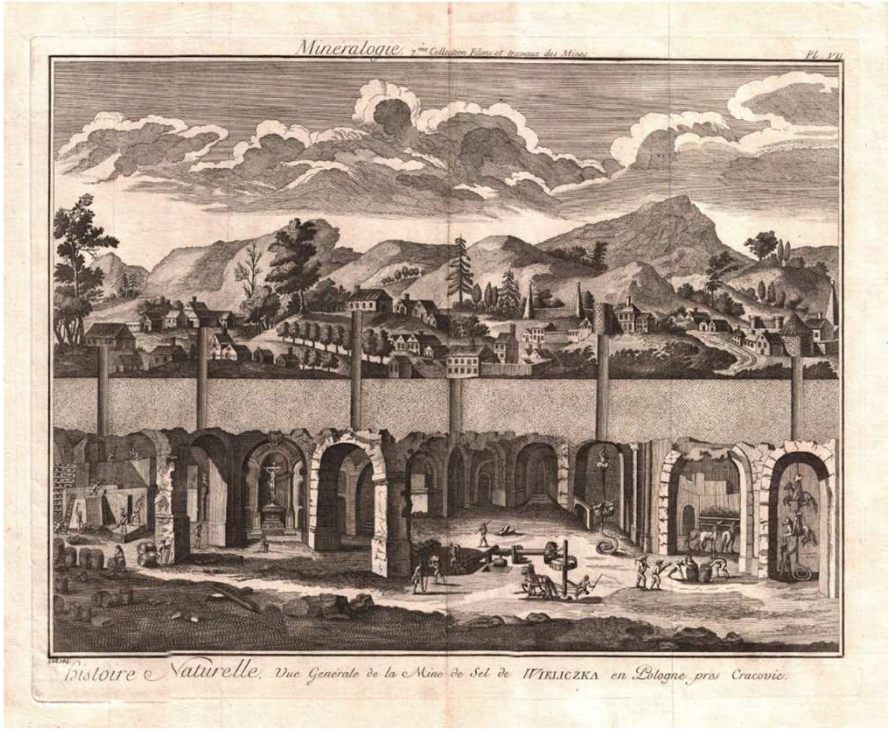
DES SCIENCES. 493

MÉMOIRE
SUR
LES MINES DE SEL DE WIELICZKA
EN POLOGNE.

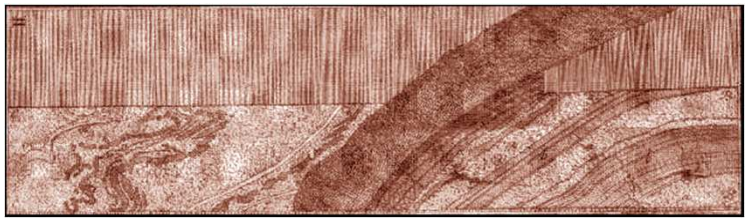
Par M. GUETTARD.

LES Mines de sel de Wieliczka ont été l'objet de la curiosité de la plupart des Voyageurs qui ont passé dans les environs : presque tous ceux qui en ont écrit en ont parlé d'une façon qui tient du merveilleux ou de l'enthousiasme ; la profondeur de ces mines a été comparée par quelques-uns aux abîmes les plus profonds ; je ne dis pas assez, il semble, suivant eux, qu'on descend dans les enfers ; suivant d'autres,

The work of Jean-Étienne Guettard – 1762
In Histoire de l'Academie Royale des Sciences



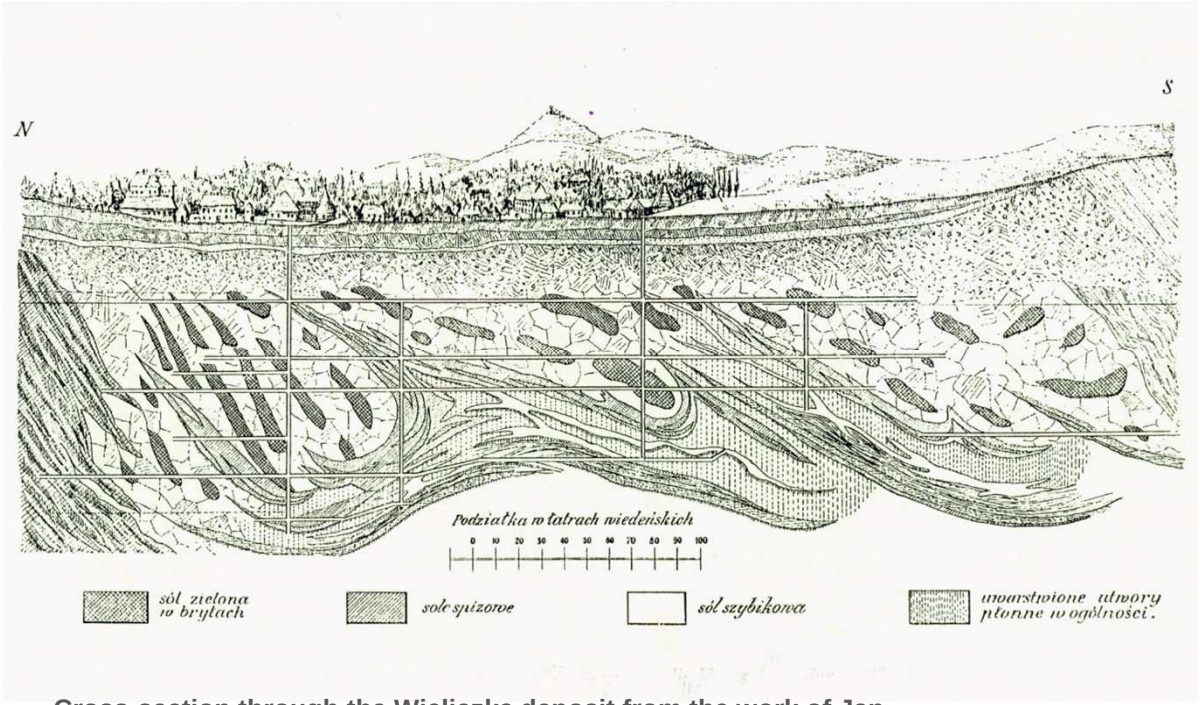
Graphic from Diderot's encyclopedia - 1768



Schober, C.G., 1750. Physikalische Nachricht von den polnischen Salzgruben Wieliczka und Bochnia
(*Hamburgisches Magazin der Gesammelte Schriften zum Unterricht und Vergnügen aus der Naturforschung und den Angenehmen Wissenschaften Überhaupt)*

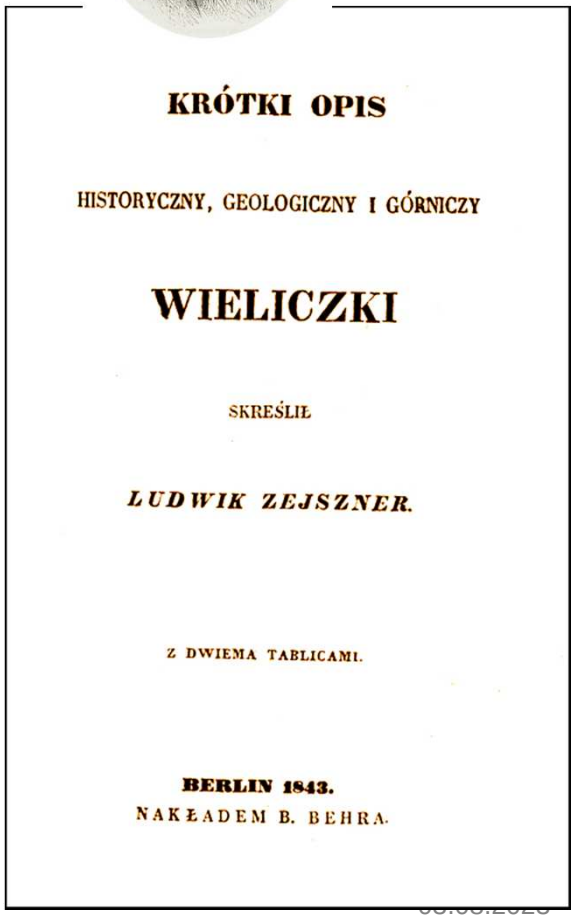
GEOLOGICAL EXPLORATION OF THE DEPOSIT

First mine mapping and scientific studies



Cross-section through the Wieliczka deposit from the work of Jan Nepomucen and Ludwig Emanuel Hrdina *Geschichte der Wieliczkaer Saline* from 1842

Hrdina brothers were surveyors of the Wieliczka mine


KRÓTKI OPIS

HISTORYCZNY, GEOLOGICZNY I GÓRNICZY

WIELICZKI

SKREŚLIŁ

LUDWIK ZEJSZNER.

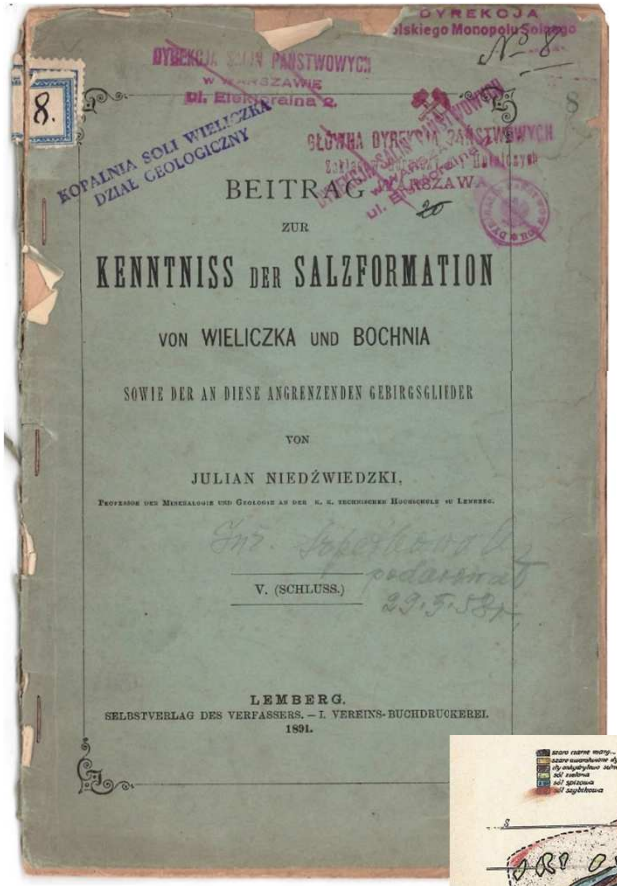
Z DWIEMA TABLICAMI.

BERLIN 1843.
NAKŁADEM B. BEHRA.

***A brief historical, geological and mining description of Wieliczka* by Ludwik Zejszner, published in 1843 in Berlin**

Ludwik Zejszner (1805-1871)) was a prominent Polish geologist

GEOLOGICAL EXPLORATION OF THE DEPOSIT



One of the researchers of the Wieliczka deposit was geologist Julian Niedźwiedzki (1845-1918)

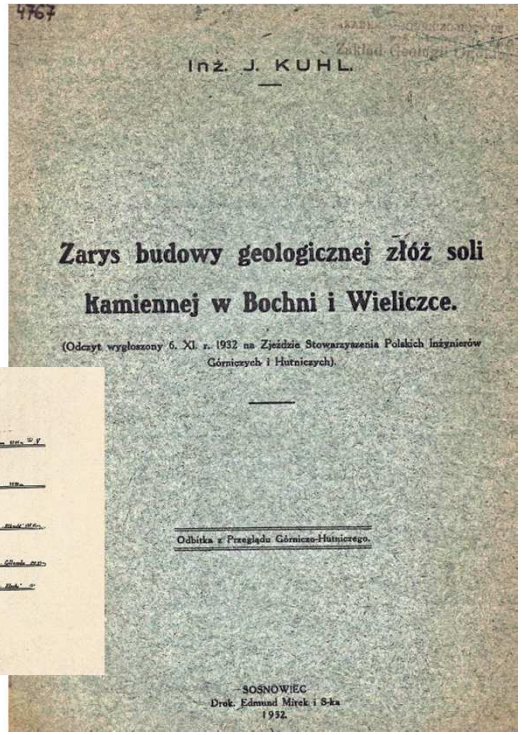
He came from a Ukrainian family

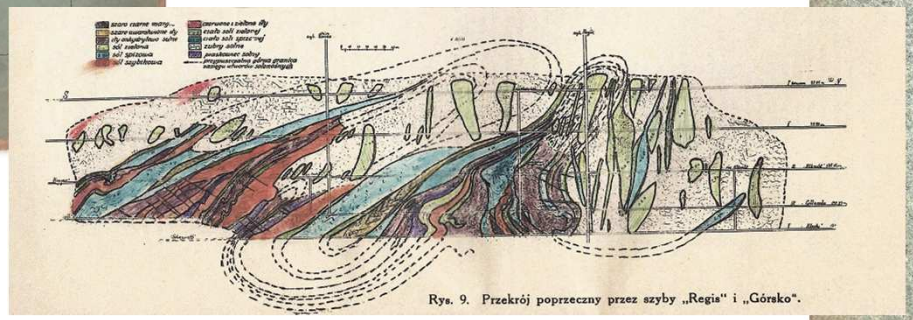
He was an explorer of the Flisz Carpathian Mountains and the rock salt deposits of Wieliczka and Bochnia, as well as the potassium salt deposits near Kalusz, Stebnik and Truskavets

His theory on the geological structure of the Wieliczka deposit was valid for many years, but today it is considered as incorrect

Another well-known geologist who dealt with issues of the geological structure of the Wieliczka deposit was Jan Kuhl (1899-1982)

He was a scientist - a professor at AGH University

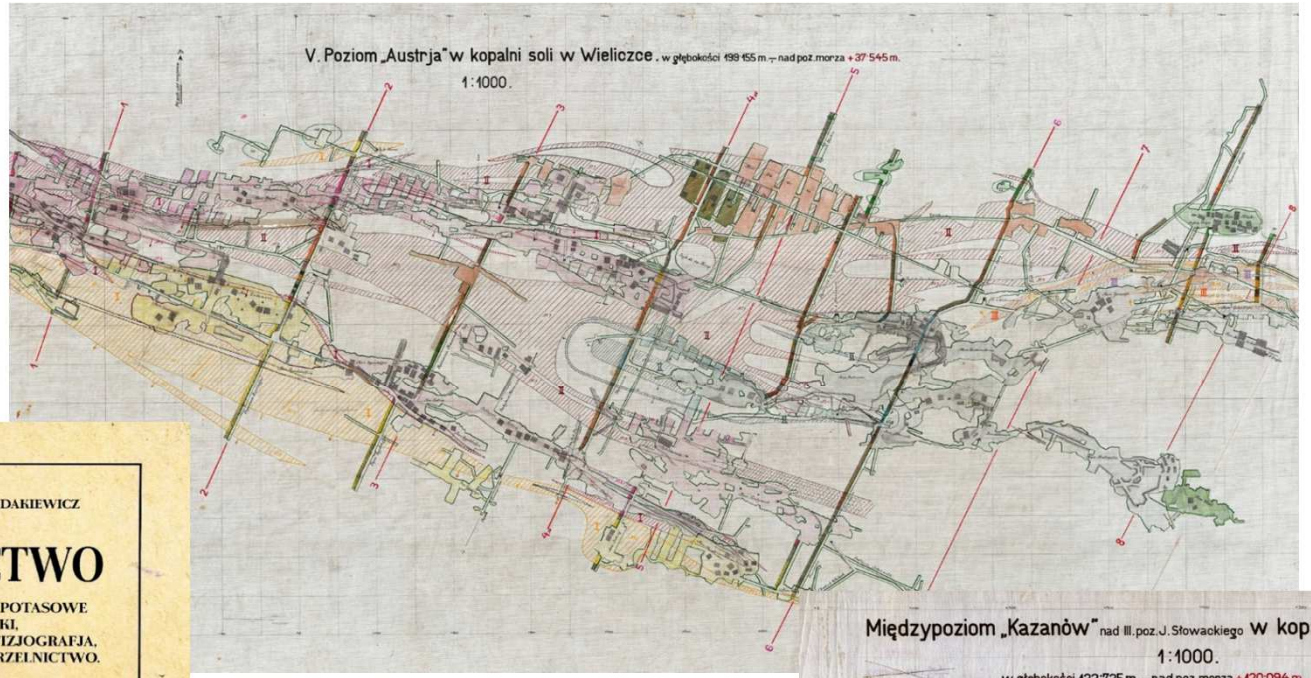


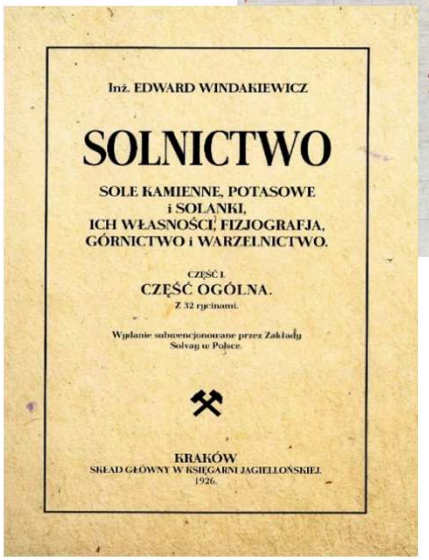


Geological cross-section through the Regis and Górsko shafts by Jan Kuhl

GEOLOGICAL EXPLORATION OF THE DEPOSIT

Geological maps from the 1920s and Edward Windakiewicz work



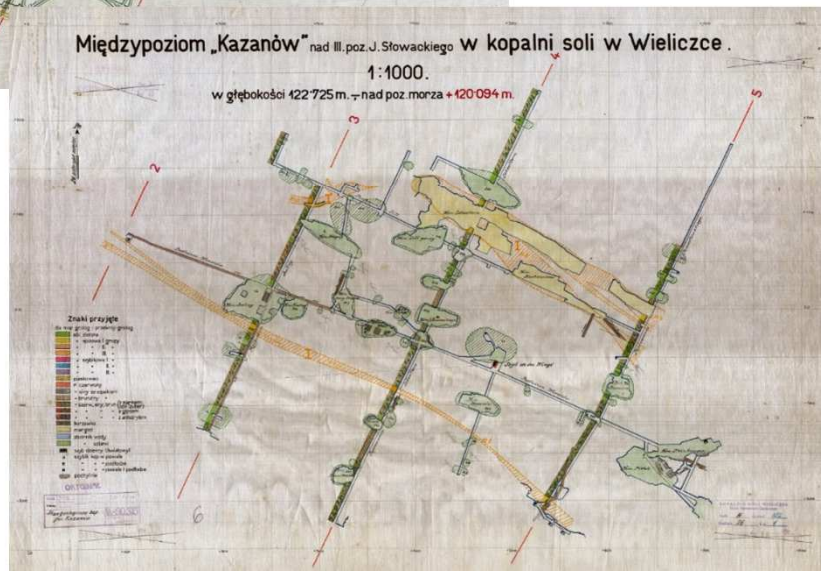


Edward Windakiewicz (1858- 1942) - salt engineer, manager of mining works in Wieliczka mine

Scientist, lecturer at the Academy of Mining (today's AGH)

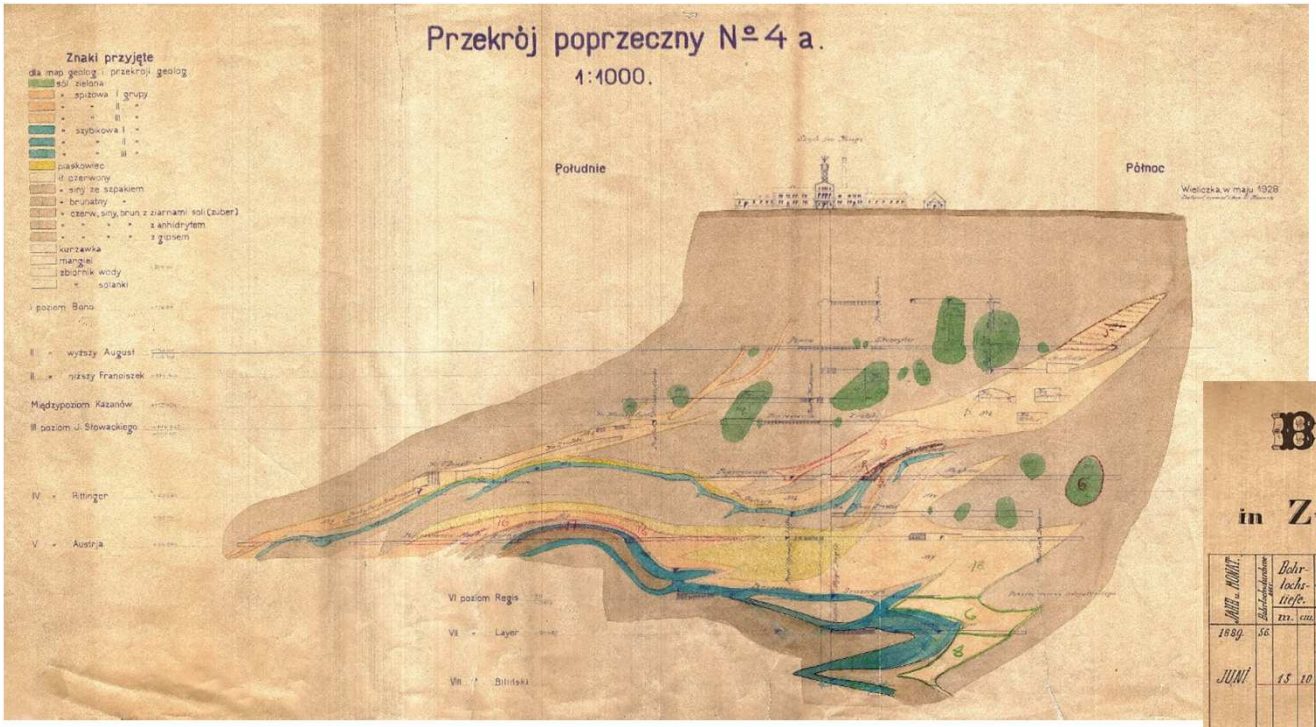
Author of five volumes of the monumental work *Salting*

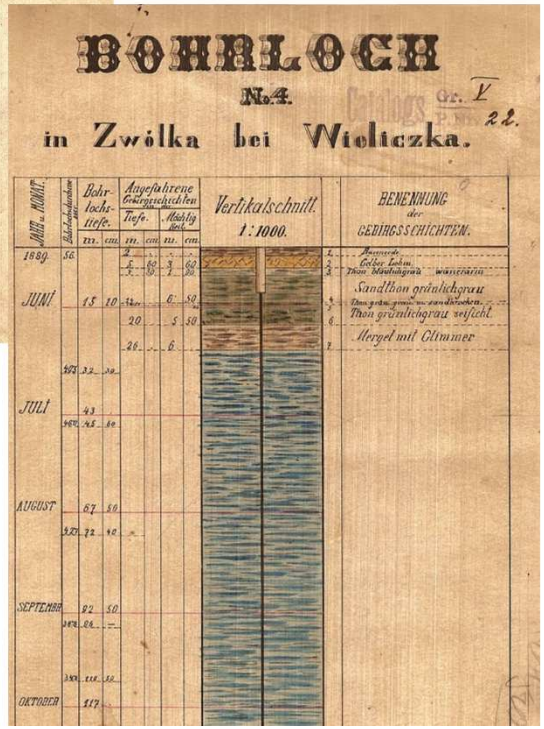
The oldest of those arrested during the Sonderaktion Krakau in October 1939, Edward Windakiewicz. He was imprisoned in German concentration camps



GEOLOGICAL EXPLORATION OF THE DEPOSIT

Examples of other archival geological documents





In the 1920s, employees of the Surveying Department of the Wieliczka Mine developed then-modern maps and cross-sections showing the Wieliczka salt deposit

A fragment of the profile of borehole no. 4, with which new parts of the deposit were recognized in the years 1889-1893

At the end of the 19th century, four boreholes with depths exceeding 400 m were drilled in the Wieliczka area

GEOLOGICAL EXPLORATION OF THE DEPOSIT

The work of Prof. Antoni Gaweł

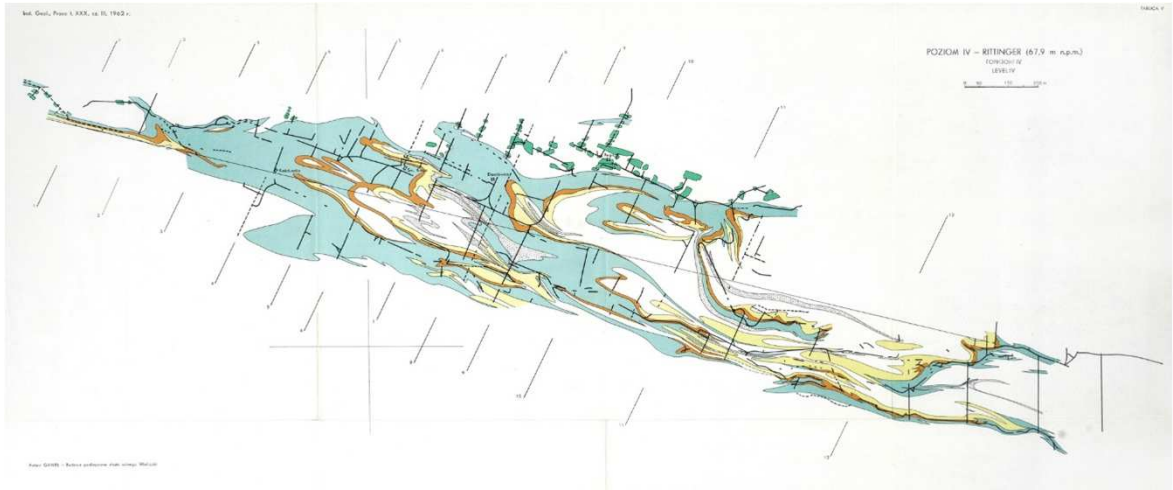
Antoni Gaweł (1901-1989) - professor of geology at the Jagiellonian University
Son of a coal miner, he had already worked at the University in the department of mineralogy since 1923

He was the youngest scholar arrested by the Germans during the Sonderaktion Krakau in October 1939, imprisoned in the Dachau and Sachsenhausen concentration camps

After his release, he took a job at the Amt fur Bodenforschung, the former Polish Geological Institute included in the German geological survey

As part of his professional duties, he was employed at the Wieliczka mine, where he mapped the workings from 1942 to 1943

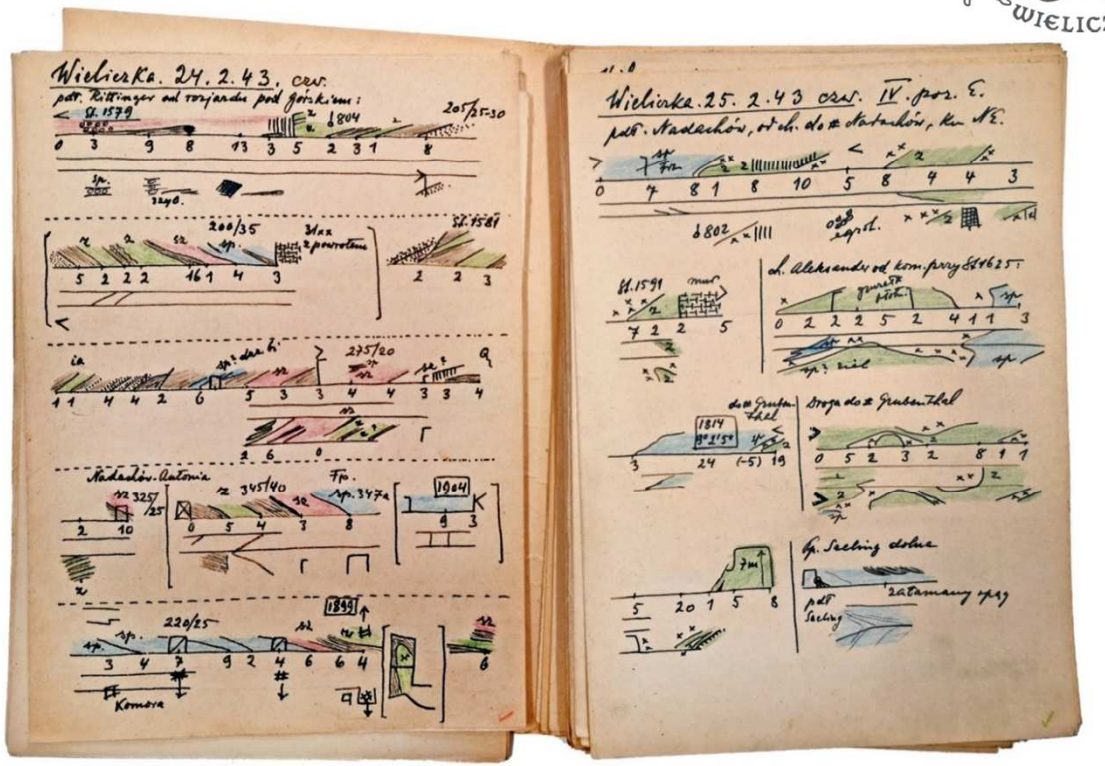
In 1962, on the basis of his wartime work, he published the work *The geological structure of the Wieliczka salt deposit*, which became the foundation of modern geology of the Wieliczka salt deposit



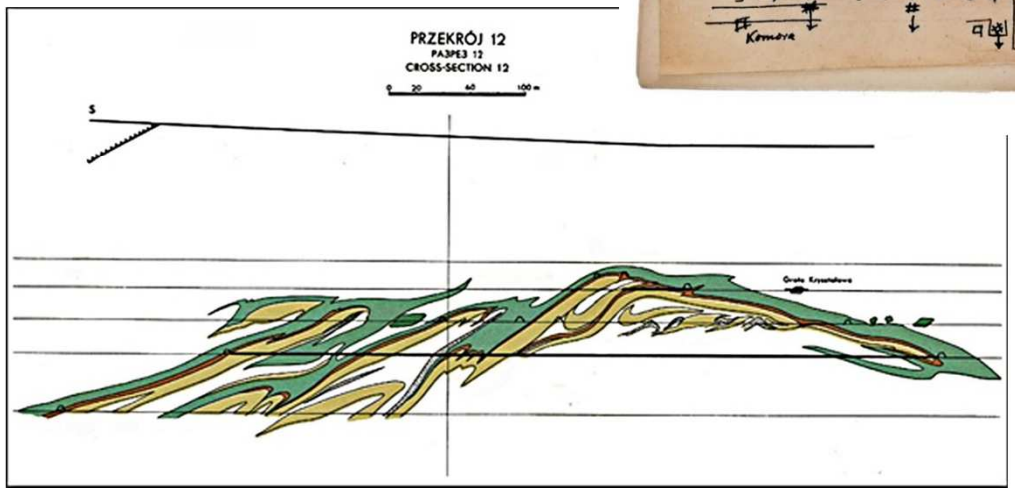
Level IV map by Antoni Gaweł

GEOLOGICAL EXPLORATION OF THE DEPOSIT

The work of Prof. Antoni Gaweł



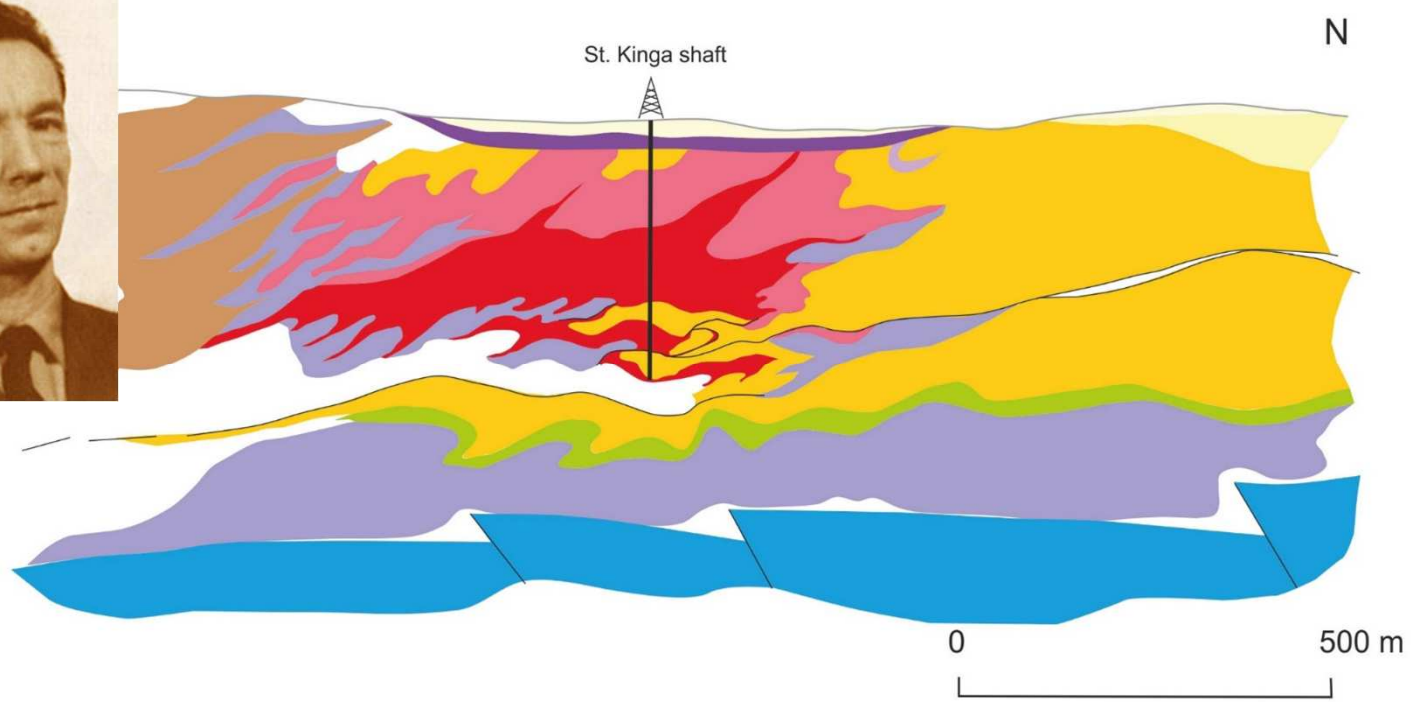
Antoni Gawel's field notebooks with mapping of underground galleries in February 1943



Cross-section No. 12 from a 1962 study by Antoni Gawel

GEOLOGICAL EXPLORATION OF THE DEPOSIT

The work of Prof. Poborski



Cross-section through the Wieliczka deposit by Jozef Poborski and Kamila Skoczylas Ciszewska from 1963, considered the classic image of the deposit and its surroundings

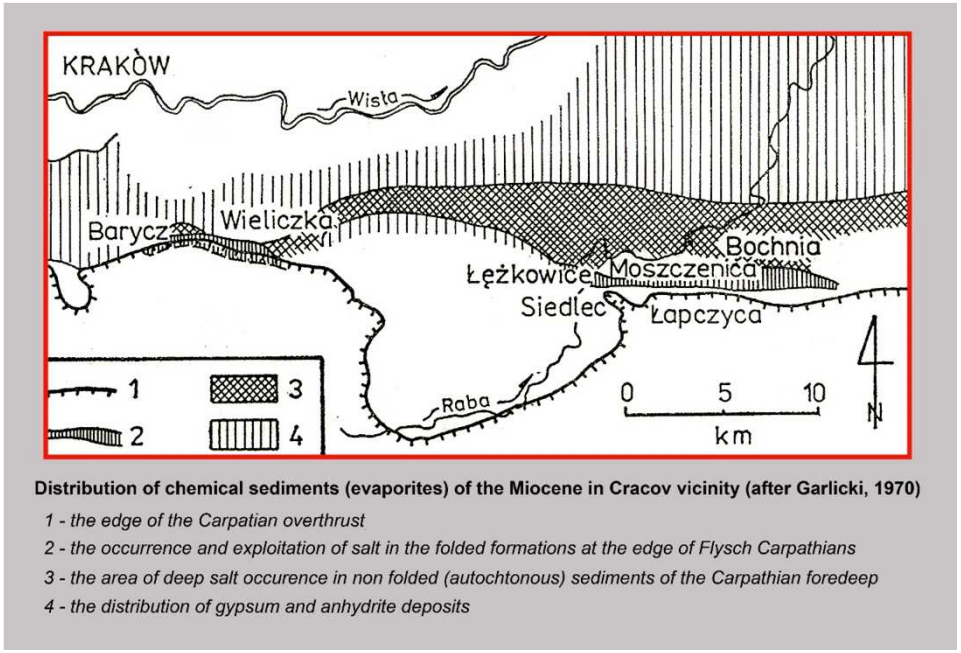
Józef Poborski (1912-1998) was a professor at the AGH University in Krakow

Extremely meritorious in the study of salt deposits, including the Wieliczka, Bochnia and Kłodawa deposits

Called "the pope of Polish salt geologists"

GEOLOGICAL EXPLORATION OF THE DEPOSIT

The work of other scientists



Distribution of chemical sediments (evaporites) of the Miocene in Cracov vicinity (after Garlicki, 1970)

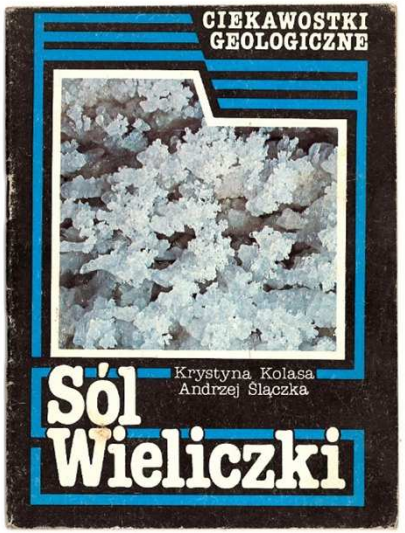
1 - the edge of the Carpatian overthrust

2 - the occurrence and exploitation of salt in the folded formations at the edge of Flysch Carpathians

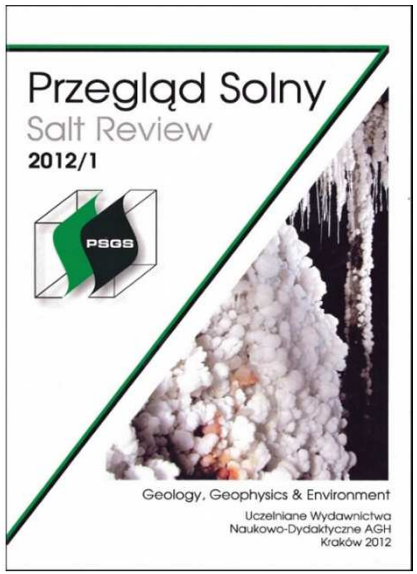
3 - the area of deep salt occurence in non folded (autochtonous) sediments of the Carpathian foredeep

4 - the distribution of gypsum and anhydrite deposits

Map by Aleksander Garlicki



Popular study *Salt of Wieliczka* by Andrzej Ślączka and Krystyna Kolasa



***Salt Review* published by The Polish Salt Mining Exploration**

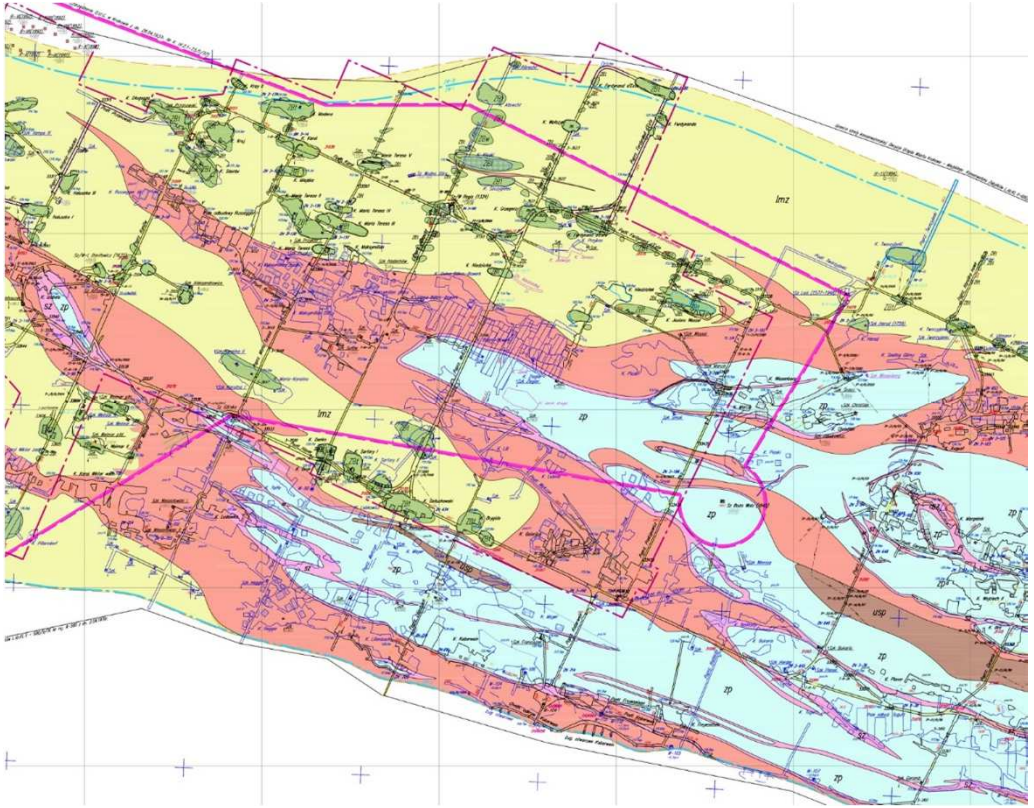
Important geologists for the study of the Wieliczka deposit are Prof. Aleksander Garlicki, Prof. Andrzej Ślączka (1931-2023) and many others

Contemporary research on the issues of the deposit is currently being conducted, among others, by Andrzej Szybist (University of AGH), Prof. Krzysztof Bukowski (University AGH), Prof. Zbigniew Sawłowicz (Jagiellonian University), Prof. Zofia Alexandrowicz (Polish Academy of Sciences) or Prof. Piotr Krzywiec (Polish Academy of Sciences)

GEOLOGICAL EXPLORATION OF THE DEPOSIT

Examples of contemporary geological maps

An section from the geological map of Level I (left) and Level III (below)

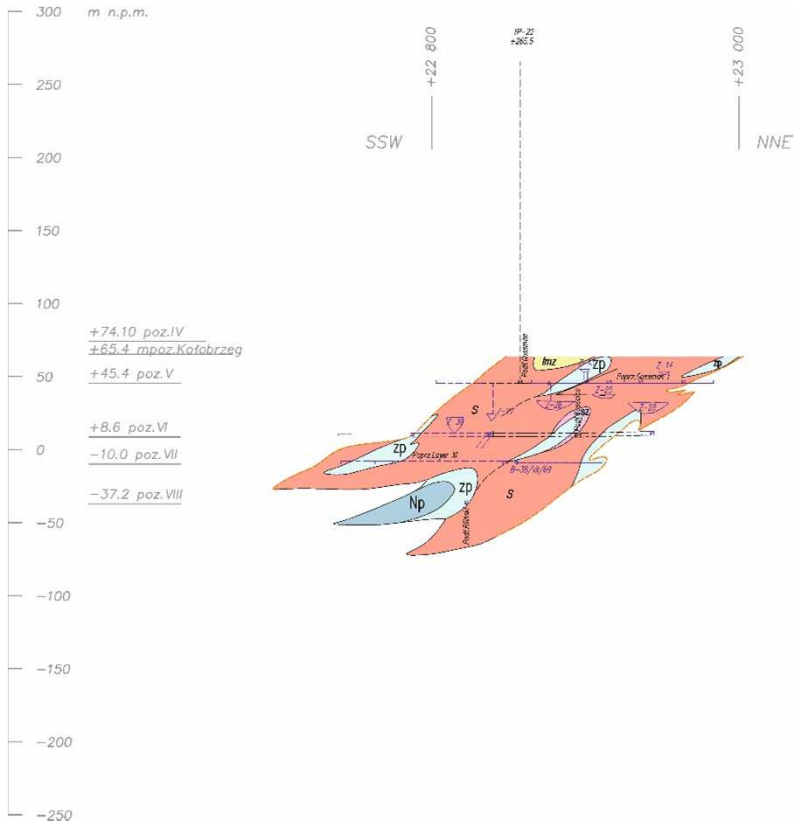


The result of many years of work by geologists and surveyours - both scientists, but especially the mine's service, - are the contemporary maps

Their creation consisted of the work of group of people, throughout the years.

GEOLOGICAL EXPLORATION OF THE DEPOSIT

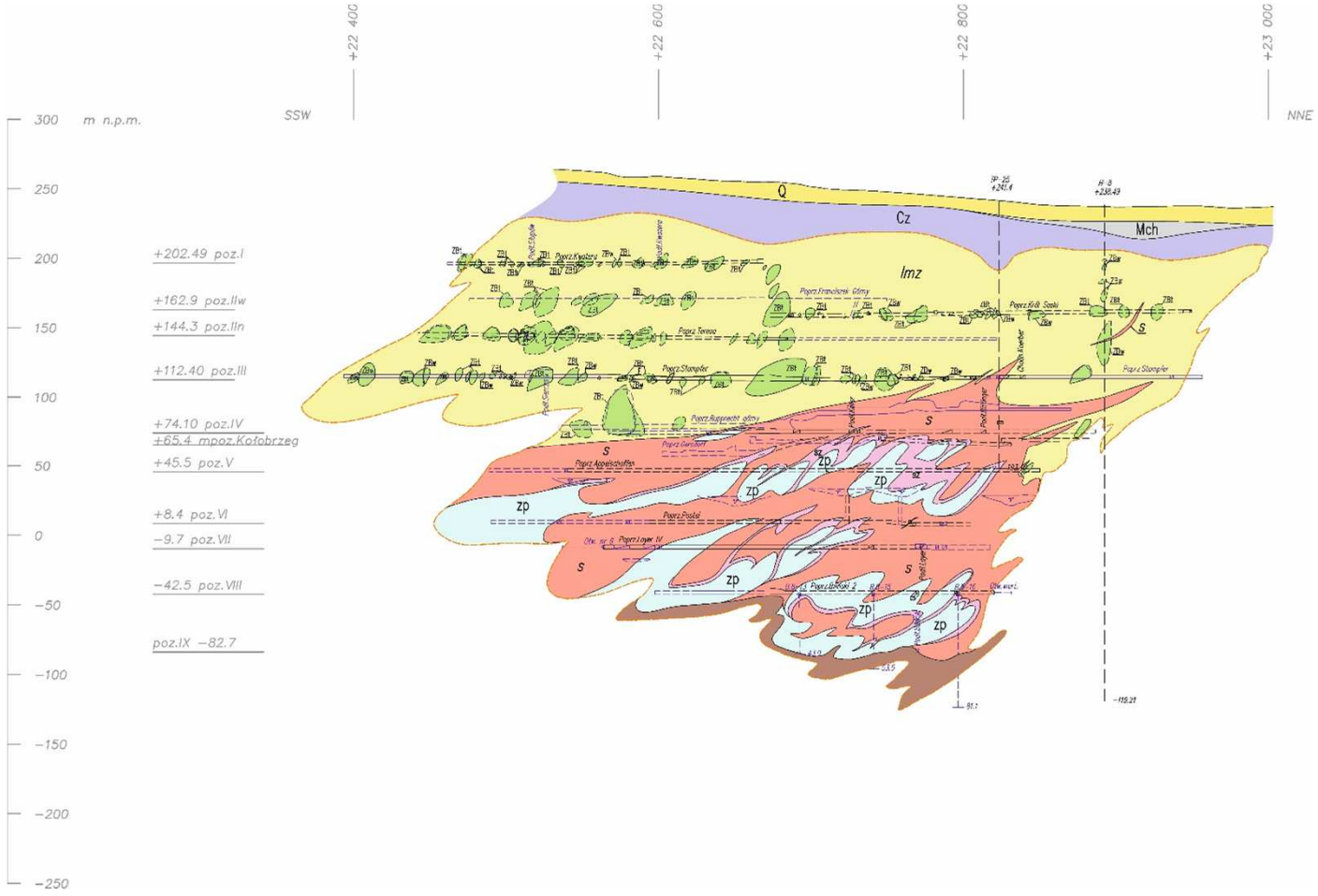
Example of a modern geological cross-section



Geological cross - section nr I

GEOLOGICAL EXPLORATION OF THE DEPOSIT

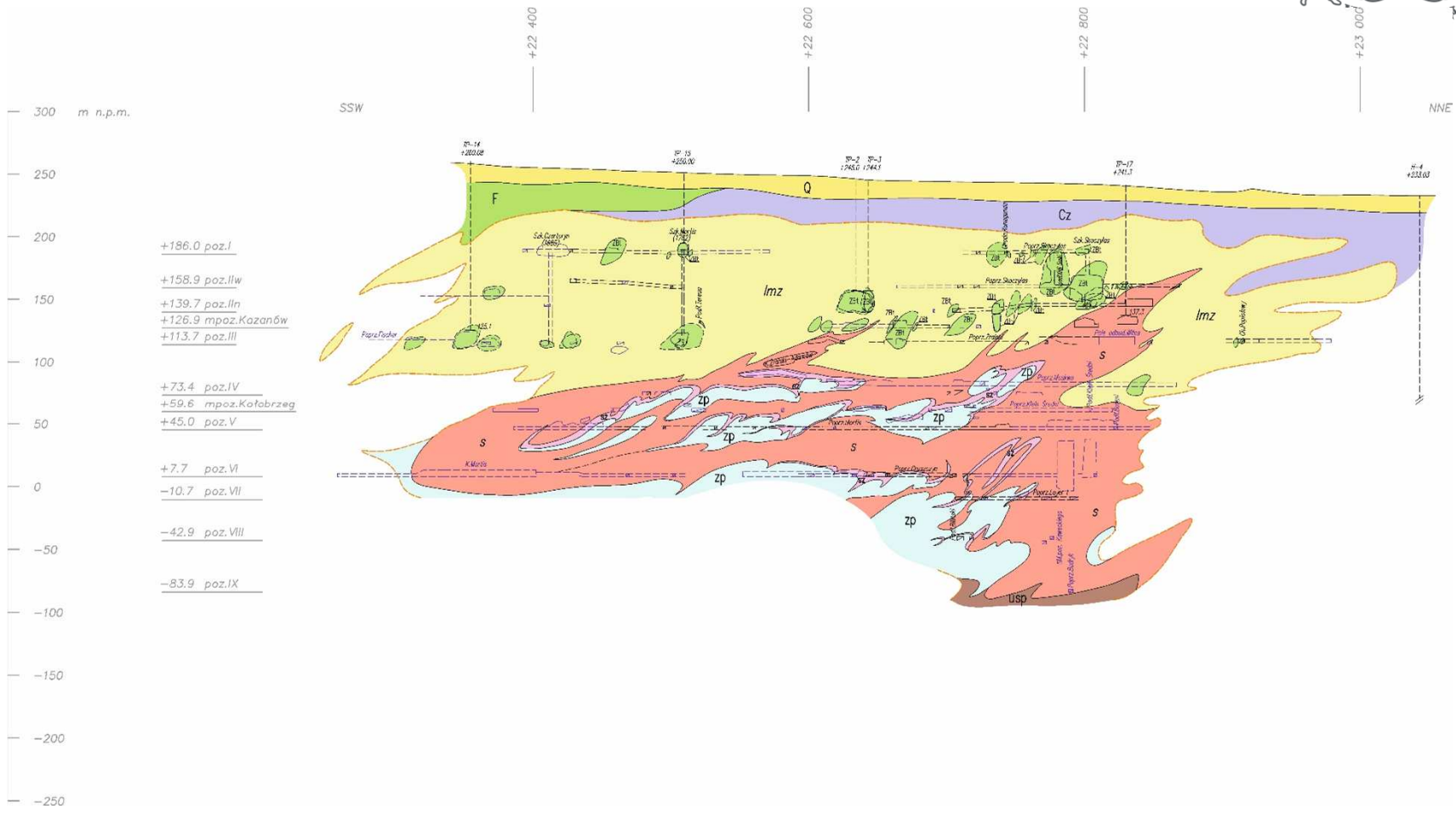
Example of a modern geological cross-section



Geological cross - section nr II

GEOLOGICAL EXPLORATION OF THE DEPOSIT

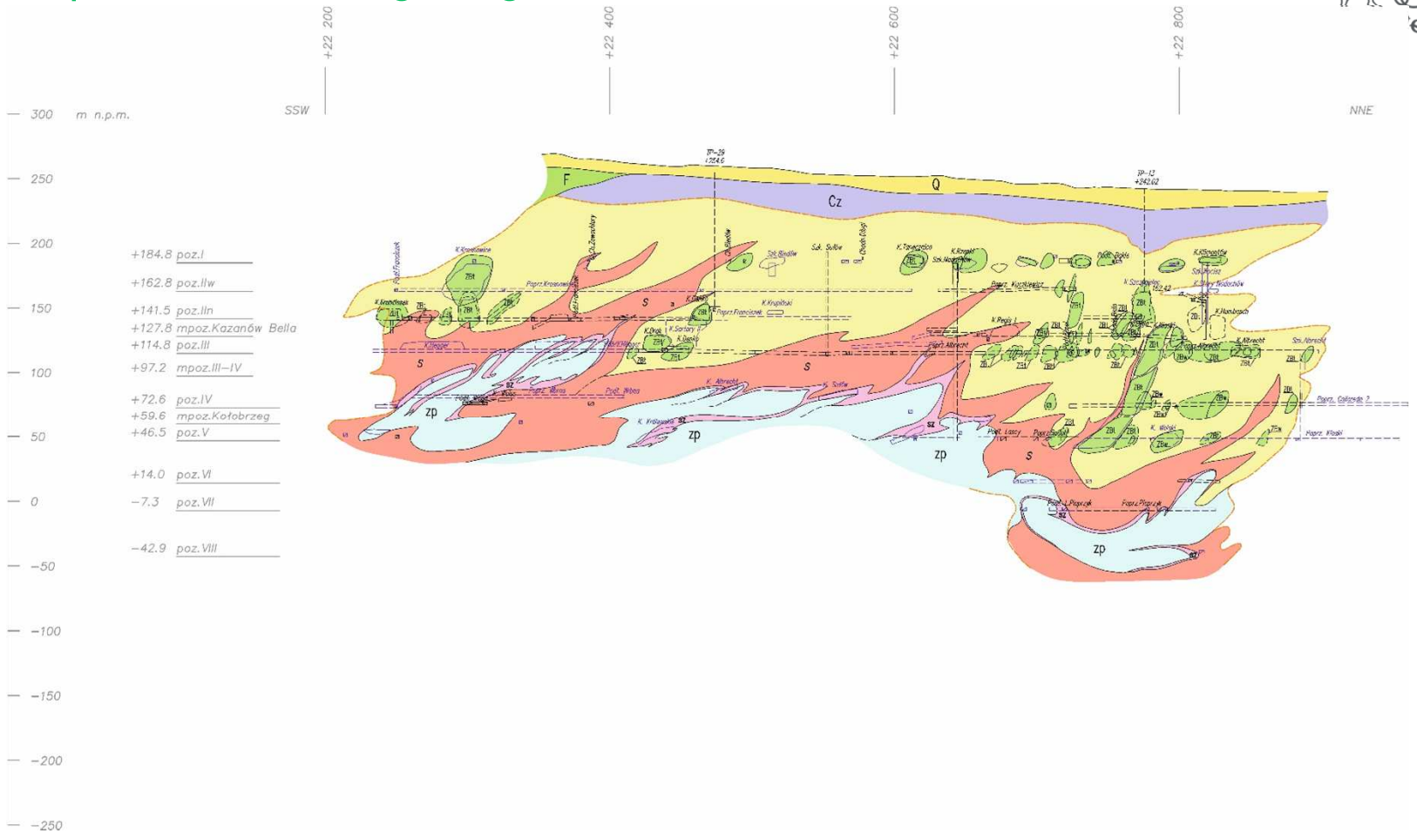
Example of a modern geological cross-section



Geological cross - section nr III

GEOLOGICAL EXPLORATION OF THE DEPOSIT

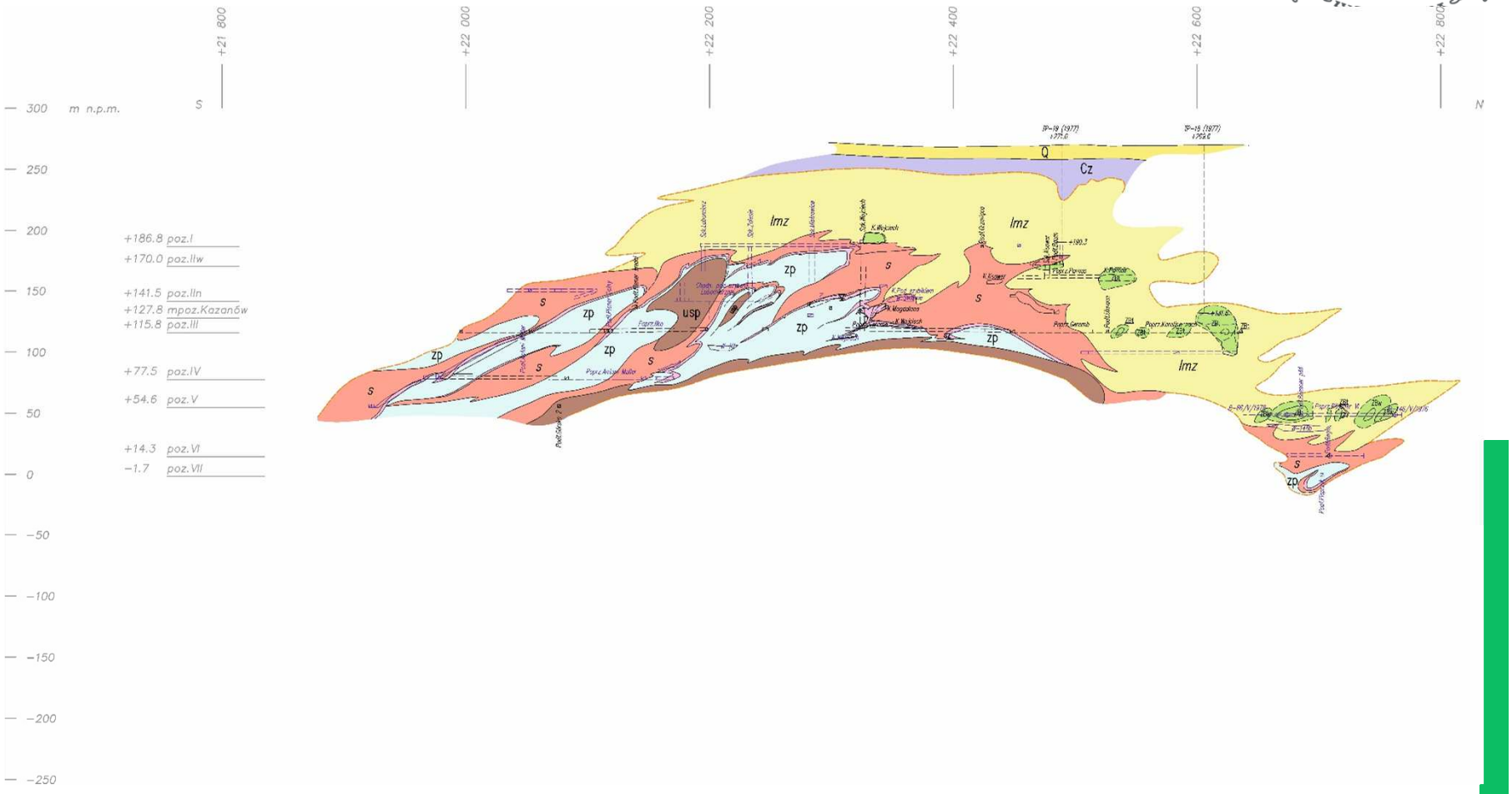
Example of a modern geological cross-section



Geological cross - section nr V

GEOLOGICAL EXPLORATION OF THE DEPOSIT

Example of a modern geological cross-section



Geological cross - section nr VI

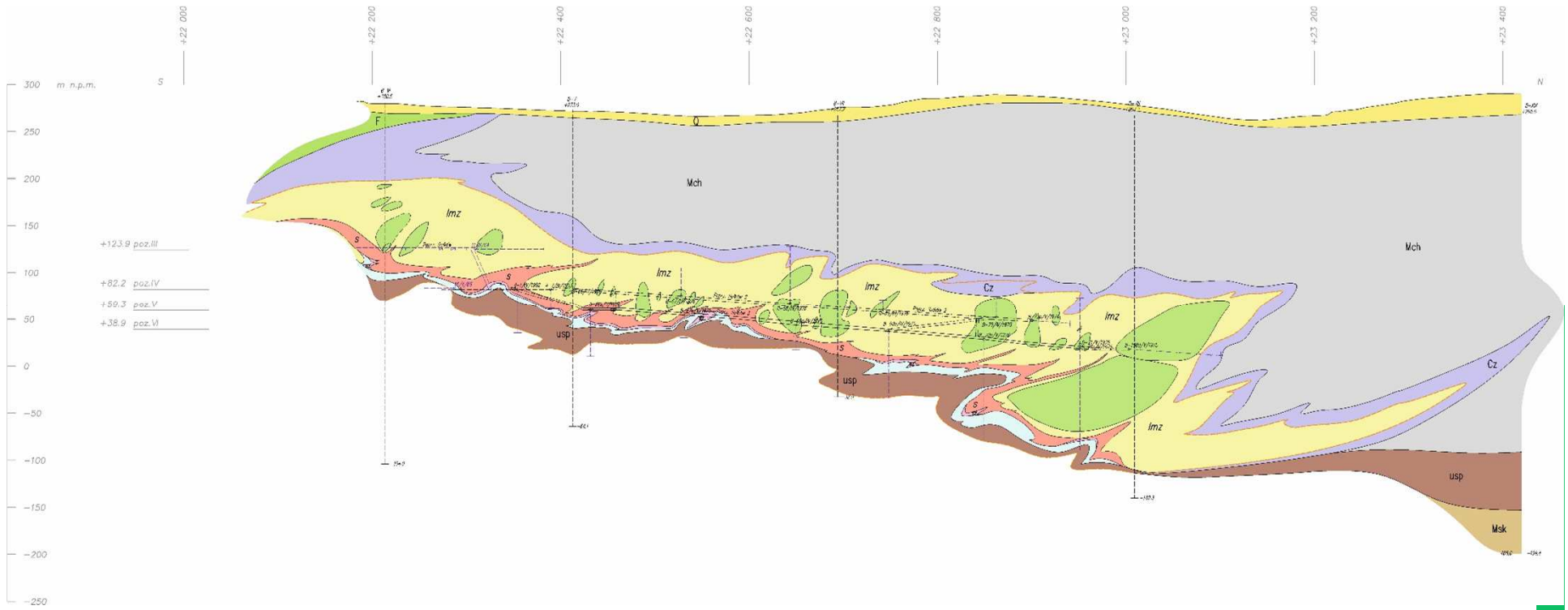
GEOLOGICAL EXPLORATION OF THE DEPOSIT

Example of a modern geological cross-section

Geological cross - section nr VII

GEOLOGICAL EXPLORATION OF THE DEPOSIT

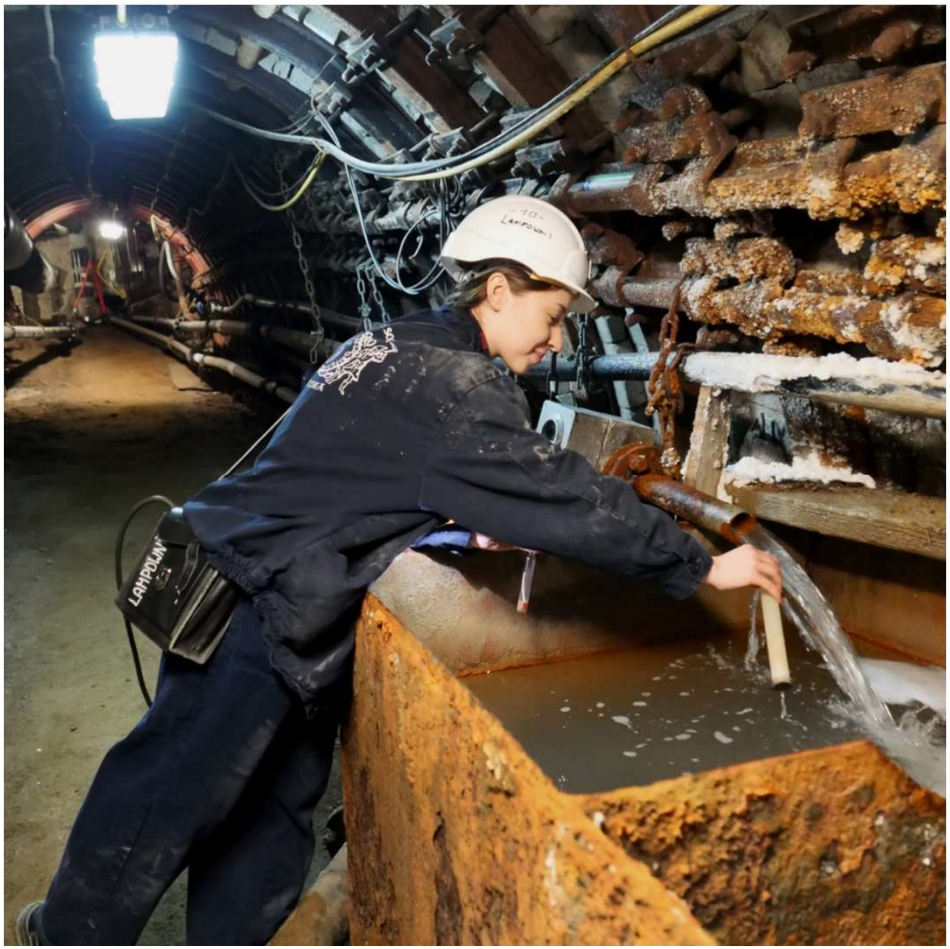
Example of a modern geological cross-section



Geological cross - section nr VIII

THREATS TO THE WIELICZKA SALT MINE

Water hazard



The main hazard for Wieliczka Salt Mine is the water hazard

The main source of dangerous inflows to the Wieliczka mine is the Chodenice beds

Currently there are 143 leaks, with a total inflow 14,79 m^3/h and average concetration NaCl 130 g/dm^3 (full saturation of brines is approximately 340 g/dm3 NaCl)

85 percent of the inflow comes from three major inflows

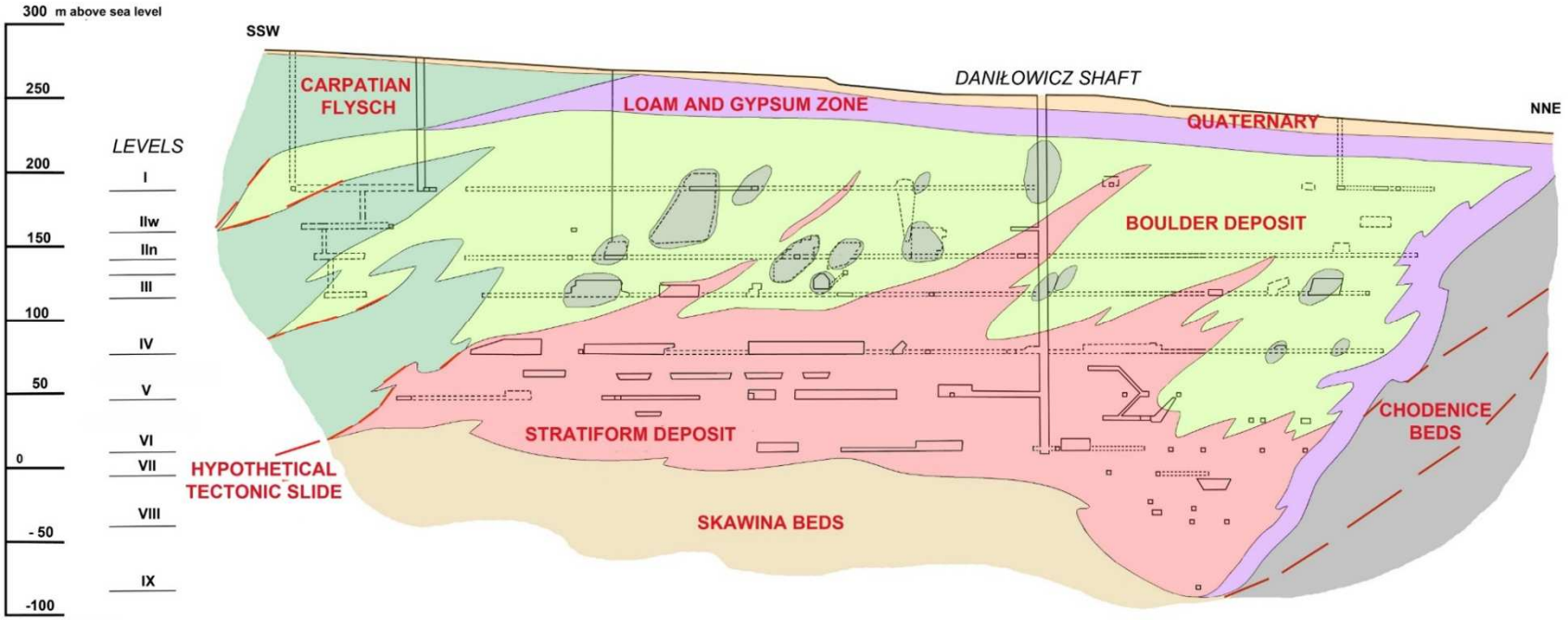
Most of the leaks are characterized by low discharge and full saturation of NaCl

These leaks are monitored and successively eliminated

Monitoring of the WVII - 16 inflow, the largest in the mine in terms of inflows - 60 percent of the total inflow to the mine

WIELICZKA SALT DEPOSIT

Simplified geological cross-section through the Wieliczka deposit



Permabilty of chodenice beds is about $10x^{-6}$ – 10^{-9} [m/s]

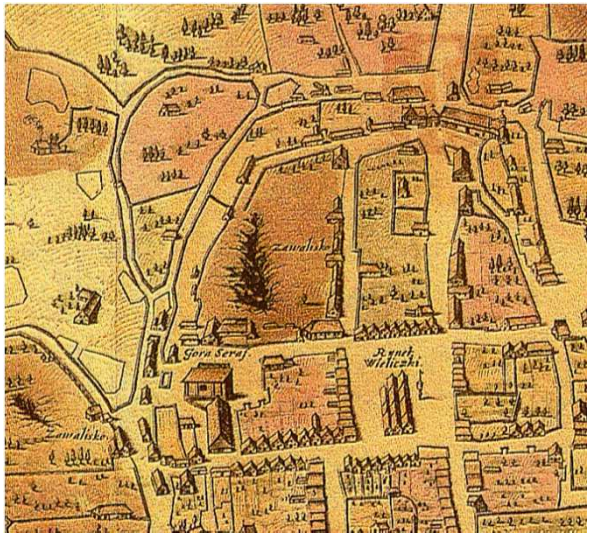
THREATS TO THE WIELICZKA SALT MINE

Hazard of collapse

Another hazard of the mine is the threat of a collapse

In the history of the mine there have been more than 20 surface collaps of chambers

Note that directly above the mine is the town of Wieliczka



A fragment of a map of Wieliczka by Marcin German

The surface collaps of chamber is marked in the center

THREATS TO THE WIELICZKA SALT MINE

Mine safety work

In order to eliminate the threat of collapse, most of the mine is being backfilling by sand

Chambers or corridors with water inflows are liquidated in a watertight way by cement slurry

Chambers are protected useing anchoring or wooden support

THREATS TO THE WIELICZKA SALT MINE

Mine safety work

Geological work - camera inspection of borehole making by mine geologists

Corridors reconstruction

WIELICZKA SALT DEPOSIT

The Crystal Caves - a natural phenomenon

Discovered in the 19th century, the voids with large halite crystals called the Crystal Caves are now an underground nature reserve

The first concentrations of crystalline halite were found as early as 1820s

The current Crystal Caves were discovered at the end of the 19th century

WIELICZKA SALT DEPOSIT

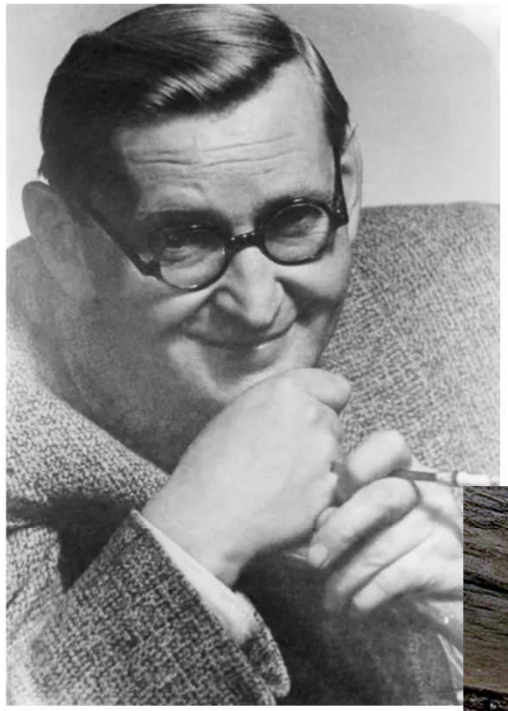
Contemporary forms of secondary crystallisation

Regular halite crystals on a fragment of wood

Salt stalactites - "macarons"and forms called "salt cauliflowers"

Cracow Saltworks Museum in Wieliczka

Alfons Długosz



Alfons Długosz (1902 -1975) – Polish painter, photographer, teacher, initiator of Cracow Saltworks Museum in Wieliczka which opened in 1951

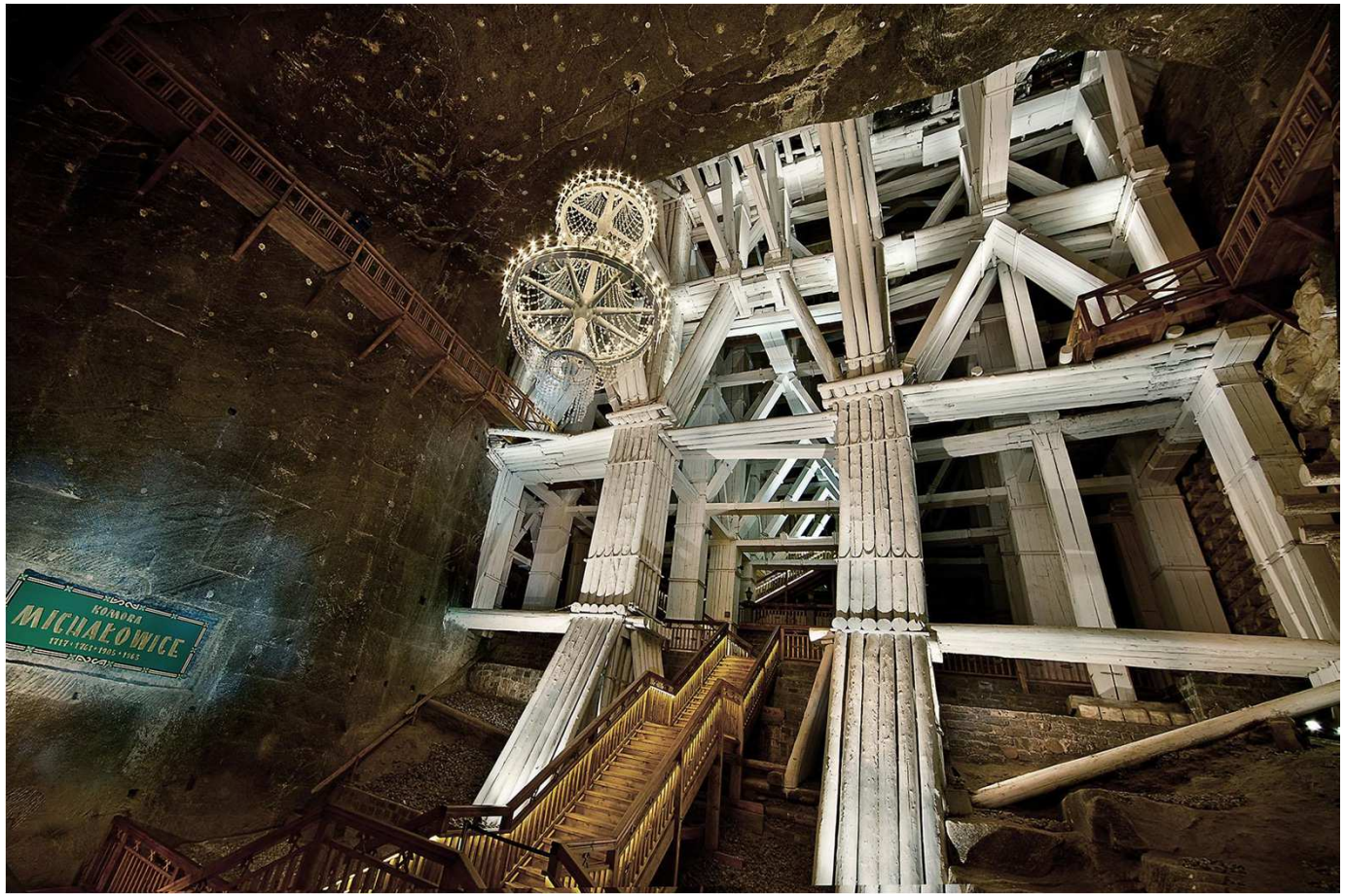
He was the long-time director of this museum

Museum collections are avaible both at the Castle headquarters and underground in chambers

Krakow Saltworks Museum in Wieliczka is the largest mining museum in the World

Cracow Saltworks Museum in Wieliczka
UNESCO

In 1978 Salt Mine „Wieliczka” was added to the UNESCO World Cultural and Natural Heritage List



WIELICZKA SALT MINE TODAY
Tourism

The tourist route runs throug mine from level I to level III, is about 3.5 km long

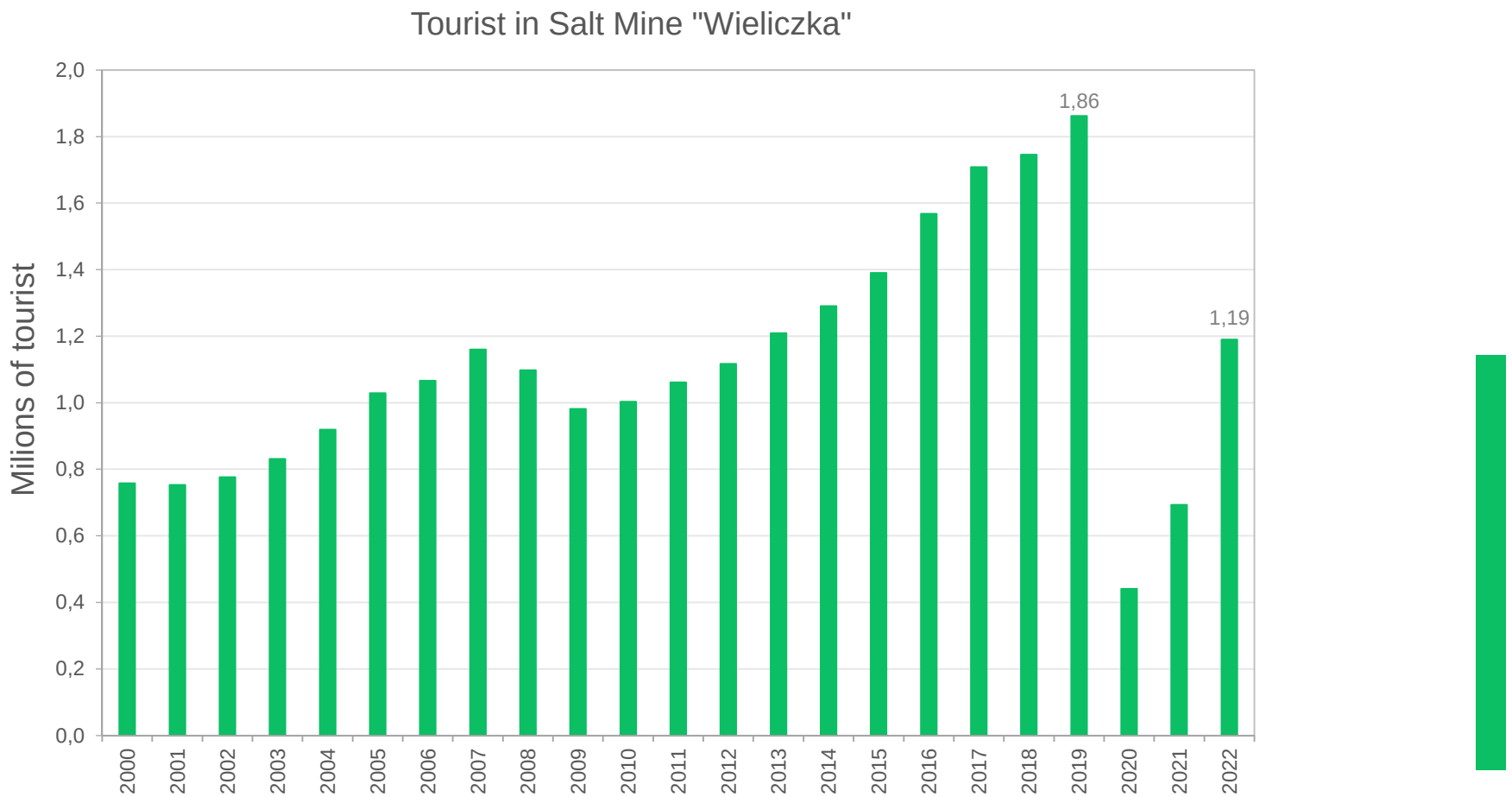
The mine was visited by 1 million 120 thousand tourists in 2022

The record year in this regard was 2019, when the mine was visited by almost 2 million people from all over the world

In addition to the basic tourist route, there are also specialized routes, such as the Mining Route

Underground, the mine also hosts classes for students of gelogy, geodesy, mining and other earth science majors

WIELICZKA SALT MINE TODAY
Tourism



WIELICZKA SALT MINE TODAY

Health protection

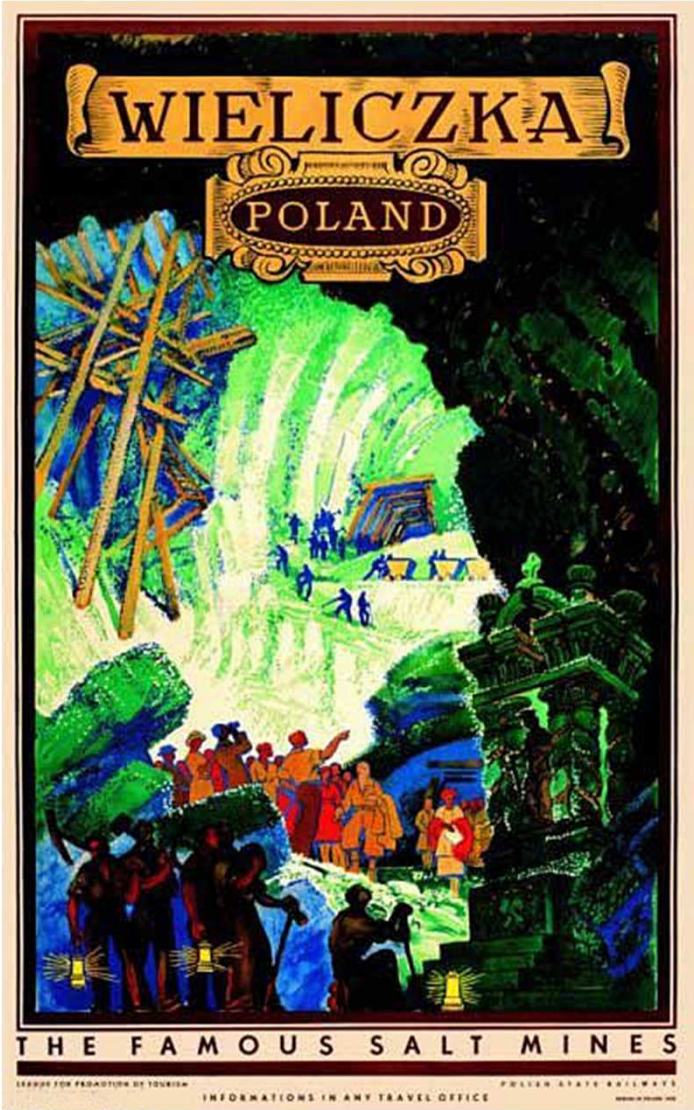
Research into the effects of underground microclimates on the human body was carried out as early as the first half of the 19th century by Dr. Feliks Boczkowski

In 1958, on the initiative of Dr. Mieczyslaw Skulimowski, an underground sanatorium was established in the mine (the second of its kind in the world)

In 2011 the sanatorium gained the status of a Health Resort

The Health Resort are located on the third level of the mine about 135 m underground

THANK YOU FOR YOUR ATTENTION



Wieliczka
Poster by Henryk Uziembło 1938