Miocene Salt Deposits in Poland

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ABSTRACT

Marine Miocene sediments are present in south Poland and cover the area of the entire foreland of the Polish Flysch Carpathians, extending without interruption from Silesia, through the Kraków region to the Paleozoic massif of Góry Świętokrzyskie to the north and to the eastern state boundary.

The Miocene salt-bearing formation belongs to the Tortonian and sediments with the chloride facies occur in Upper Silesia. Farther east the sediments of the chloride facies extend from Wieliczka to Tarnów (near Kraków). In the Carpathian foreland two main units can be distinguished, namely an autochthonous unit and an overthrust one. Evaporites, which occur in the overthrust unit, were folded and thrust from the south, over the autochthonous unit.

In the tectonic setting in front of the Carpathian thrust belt, salt deposits occur at Wieliczka, Łężkowice-Siedlec, Moszczenica-Łapczyca, Bochnia and in the Tarnów vicinity. The Wieliczka deposit has been mined for a thousand years and the Bochnia deposit for some 700 years. Salt deposits at Łężkowice-Siedlec and Moszczenica-Łapczyca were discovered as a result of exploration work carried on by the Geological Institute in the years 1956–1968.

Within the autochthonous unit, in Upper Silesia, salt associated with clay-anhydrite layers overlies the Carboniferous coal basin sediments. The thickness of evaporites reaches 50 to 80 meters. Farther east evaporites of the chloride facies within the autochthonous unit extend from Wieliczka to Tarnów, with an eastward increase in thickness from 40 meters near Wieliczka to about 200 meters near Tarnów.

On the area of the eastern Carpathian foreland, there are some other occurrences of the Miocene salt, which are of less importance, however.

INTRODUCTION

Miocene rocks in Poland are both continental and marine in origin. The continental sediments are present in southwestern Poland and cover large areas in the central and northern parts of the country. Marine Miocene sediments are present in south Poland and cover the area of the entire foreland of the Polish Flysch Carpathians, extending without interruption from Silesia, through the Kraków region to the Paleozoic massif of Góry Świętokrzyskie to the north (Kielce region) and to the eastern state boundary. Figure 1 shows the approximate extent of marine Miocene sediments northward of the Carpathian overthrust. Boreholes piercing the Carpathian Flysch have recorded occurrences of marine Miocene sediments below Flysch nappes cover, several kilometers to the south of the Carpathian overthrust boundary. The thickness of the discussed sediments varies greatly, ranging from a few hundred meters in the western and northern parts to over 3,000 meters in the eastern part of the Carpathian foreland.

The marine Miocene consists of clays, sands and evaporites. Although the evaporites comprise only a small part of the vertical profile of marine deposits, they are widespread in the sedimentary basin and thus form an important marker horizon. The Miocene salt-bearing formation containing the evaporite horizon belongs to the Tortonian (Fig. 2) and is subdivided into 3 members: Skawina beds (sediments underlying evaporites), Wieliczka beds (evaporites), and Chodenice beds (sediments overlying evaporites).

The Miocene salt deposits were the cradle of the Polish mining industry. In the vicinity of Wieliczka, the beginnings of salt-mining took place in the Middle Ages. In the earliest times salt was obtained there by roasting and boil-

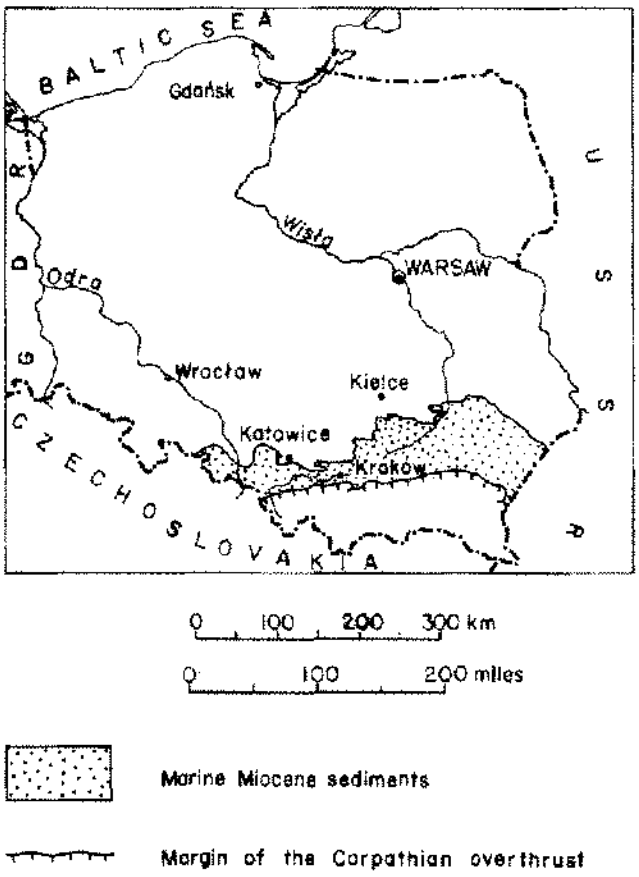

Figure 1. Extent of marine Miocene sediments northward of the Carpathians.

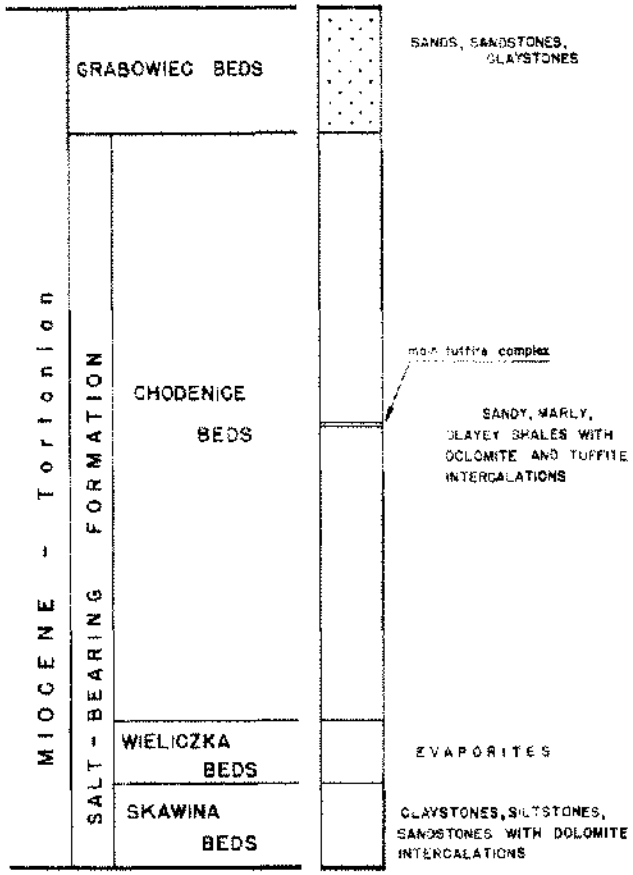

Figure 2. Stratigraphic position of the Miocene salt-bearing formation.

ing to dryness salt brine obtained from brine wells. Boiling apparatus from the tenth and eleventh centuries was discovered during recent archaeological excavations. Written documents show that as early as the eleventh century there was a great brine producing center at Wieliczka ("Magnum Sal" in Latin). Rock salt, however, was discovered later. By the thirteenth century there were rock salt mines at Wieliczka and Bochnia. These salt-mines were the king's property and were administered by managers designated by royal orders. As a matter of fact, during medieval history of Poland, the salt mines were the main source of income to the royal treasury.

I am grateful to Robert J. Hite (U.S. Geological Survey, Denver, Colorado) for his comments and critical review of the manuscript.

MIOCENE SALT-BEARING FORMATION AND ITS TECTONIC SETTING

In Silesia the Miocene salt-bearing formation overlies the Carboniferous. Between the Gory Swietokrzyskie massif in the north and the area of Kraków, Tarnow and Debica in the south it overlies Jurassic or Cretaceous rocks. East of Rzeszow it rests on the Precambrian. In the northern and northwestern part of the Carpathian foreland there are no underlying clayey sediments and the evaporites of the salt-bearing formation lie directly upon older, Paleozoic and Mesozoic rocks. Within the Wieliczka beds, three facies have been distinguished:

1. carbonate-littoral facies comprising organic limestones and mixed carbonate and detrital sediments, containing sands, sandstones and gravels;
2. sulfate facies, comprising anhydrite, gypsum and sulfur-bearing deposits;
3. chloride facies, containing rock salt with anhydrite and clay-anhydrite sediments.

Sediments of the carbonate-littoral facies occur in a broad belt extending along the northern boundary of the Carpathian foreland. The thickness of these sediments does not exceed a few tens of meters. The sulfate facies is the most extensive. It covers the Carpathian foreland from the eastern state boundary to the Krakow area and the major part of Upper Silesia. The sulfur deposits of the Tarnobrzeg region, the sulfur occurrences in Upper Silesia and in the

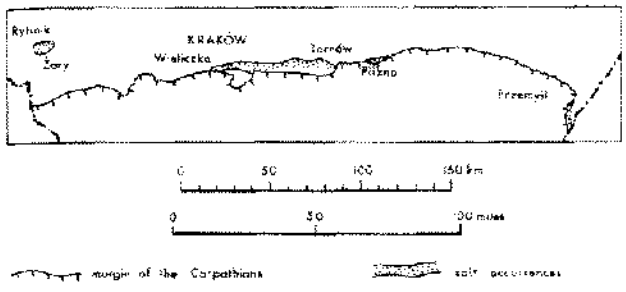

Figure 3. Map of the Miocene salt occurrences in Poland.

vicinity of Kraków are in this facies. The average thickness of the sulfate facies is 10 to 20 meters. The areal extent of the chloride facies is smaller than the other facies. In Upper Silesia, near Rybnik (Fig. 3) the chloride facies covers an oval-shaped area and is surrounded by the sulfate facies. Farther east, along the Carpathian boundary, the sediments of chloride facies extend from Wieliczka to Tarnów (Garlicki, 1971a).

In the Tortonian salt-bearing formation of the Carpathian foreland two main units can be distinguished, namely an autochthonous unit and an overthrust one. The latter sometimes is called an allochthonous element (Poborski and Skoczylas-Ciszewska, 1963, p. 348). During Late Miocene strata in the allochthon were folded in front of the Carpathian nappes and thrust from the south, over the autochthon. These tectonic features can be observed in numerous cross-sections through the marginal zone of the Miocene in front of the Carpathian thrust belt in Poland. Intense structural deformation makes it difficult to distinguish the normal sequence of strata in the allochthon. As a result of these tectonic disturbances in the overthrust unit, one can observe recumbent folds passing into imbrications, strong deformations of salt layers causing their increase and decrease in thickness, and even coarse tectonic breccia composed of salt clays with blocks of salt. In the area between Wieliczka and Tarnów along the Carpathians margin both autochthonous and overthrust units are present; in Upper Silesia only the autochthonous unit is present. North of the Carpathian margin the salt-bearing formation did not suffer any influence of the thrusting movements and the stratigraphic sequence of layers can be more easily distinguished in the autochthonous unit, particularly in the central part of the salt-bearing formation basin (Fig. 2). Clayey sediments of the Tortonian underlying the evaporites (Skawina beds) range in thickness from a few meters up to 150 meters. Deposits occurring at the bottom of the evaporites are usually represented by marly claystones and marly, clayey shales, and less frequently by siltstones with a cement composed partly of evaporites. Within these sediments numerous intercalations of chemically deposited dolomites occur, as well as abundant carbonized plant remains. In the northern part of the sedimentary basin, these deposits are of the clayey-marly type; farther to the south, the more clastic material is found, and the sediments tend to become coarse-grained or even conglomeratic. A transition to overlying evaporites is gradual, with slow increase of chloride and sulfate minerals. The thicknesses of Wieliczka beds range from 40 meters to about 200 meters, with an eastward increase in thickness. Five cyclothems can be distinguished within the evaporites. The youngest cyclothem is present only in the central part of the sedimentary basin. In general, each cyclothem begins with claystones or clayey-anhydritic sediments, with abundant admixture of silt and carbonized plant fragments, then followed by anhydritic claystones of nodular and banded structure, which in turn are followed by clayey-anhydritic shales that are fine-laminated, laminated and thinly banded. The uppermost part of each cyclothem consists of rock salt layers, except for some profiles of the youngest, fifth cyclothem, where the uppermost section is developed as anhydrite, instead of salt. The intensity of chemical sedimentation was never high enough to cause the precipitation of potassium-magnesium salts. In some of the cyclothems there are a number of marker beds, which are characterized by a more or less uniform development, and thus facilitate stratigraphic correlation in the entire sedimentary basin, in the sediments of both the autochthonous and overthrust units. For example, in the first cyclothem the key deposits are arenaceous salts; in the second they are clayey-anhydritic shales with intercalations of coarse crystalline salts, and striped salts. The basic difference between evaporites within the autochthonous unit and those within the overthrust unit is that the latter were deposited on a flysch basement, in unstable sedimentation conditions. This is indicated; among other data, by the frequent occurrence of flow (waved) structures in banded anhydrites as well as the frequent presence of exotic, clastic flysch material within the evaporites. Another typical feature of the evaporites within the overthrust unit is the occurrence of brecciated salt clays containing coarse salt crystals which reach a considerable thickness. Sediments overlying the evaporites (Chodenice beds) are usually developed as sandy, marly, clayey shales, with numerous dolomite intercalations in the lower part and tuffite intercalations in the upper part. These clayey sediments contain a large amount of salt, ranging up to 1 percent of Cl by weight. Usually about 200 to 500 meters above the top of the evaporites, over 10 meters thick complex of tuffites occurs. This complex is considered a very important marker bed. The total thickness of Chodenice beds varies from 100 meters to about 1,000 meters with respect to their position in the sedimentary basin and later erosion activity (Garlicki, 1968a, 1968b).

Salt deposits occur in both mentioned units; however, no salt deposits within the autochthonous unit have been

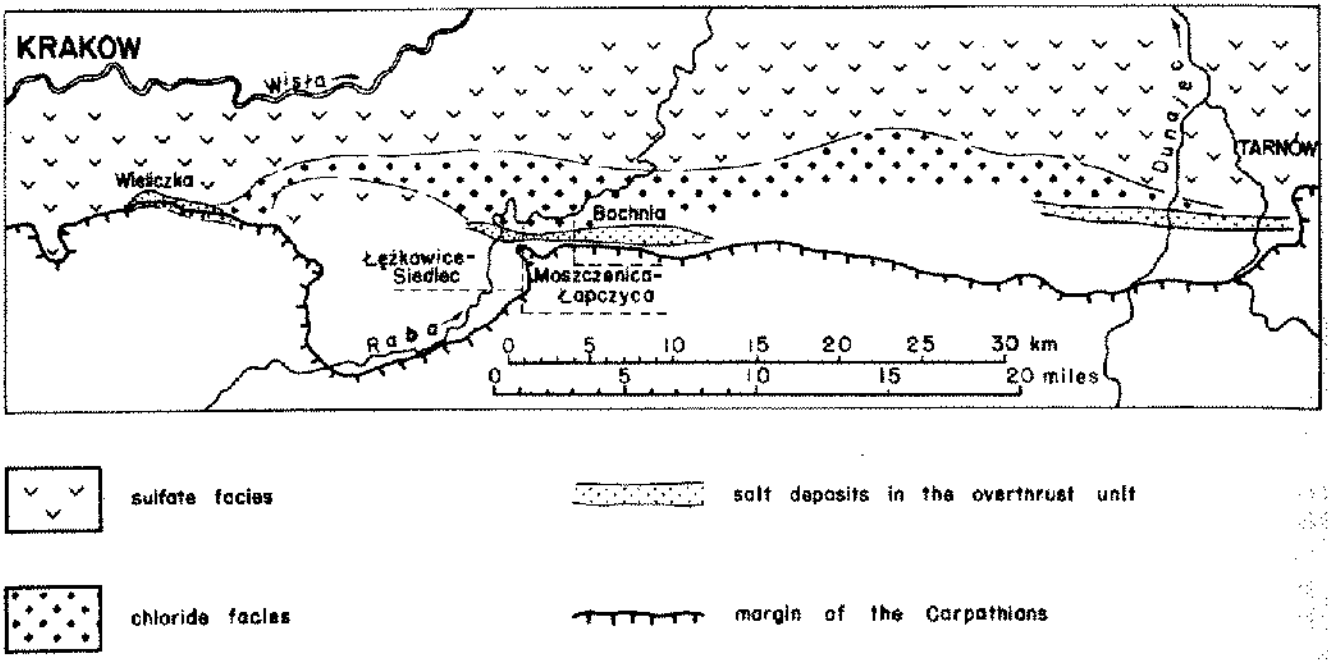

Figure 4. Map of salt deposits in the Krakow—Tarnow region.

mined so far. This is due to the relatively small thickness of salt layers of the autochthonous unit and the usually deep occurrence of these strata. Figures 3 and 4 show location of the Miocene salt deposits.

SALT DEPOSITS WITHIN THE OVERTHRUST UNIT

Wieliczka

Geological structure of the Wieliczka salt mine has been described in numerous papers already (Gawel, 1962; Poborski and Skoczylas-Ciszewska, 1963; Garlicki, 1970a). The most comprehensive publication is that of Gawel (1962), in which numerous detail cross-sections have been presented. The salt deposit at Wieliczka is 1 km wide, about 6 km long, over 300 m deep, and consists of two essential parts. The upper one is developed in the form of coarse breccia composed mainly of salt clays, with blocks of coarse-grained salt, called green salt. These blocks of irregular shape and various thickness in some places reach an extension of more than 150 meters. The lower part of the deposit is developed as a complex of salt layers strongly folded, deformed, and thrust over one another. The salt layers are interbedded with anhydrite and anhydritic clays. From the south, flysch sediments in the form of tongue-shaped wedges are squeezed into the inner part of the salt deposit.

Since the salt deposit at Wieliczka has been worked for about 1,000 years, its resources are almost completely exhausted. Present exploitation takes place in the lower part of the deposit, using the system of solution mining in underground boreholes and chambers. The western part of the deposit, called Barycz, is exploited by leaching salt with water through boreholes from the surface.

In the upper part of the mine, the old exploited area comprises a network of chambers and galleries the total length of which is about 180 kilometers. In this part of the mine an original underground touring route and a museum have been arranged. The touring route leads to the depth of 135 meters, passing through galleries, staircases and chapels carved out of salt blocks during the 17th to 19th centuries. One of the largest and most beautiful is the Chapel of Blessed Kinga. It is 54 m long, 14.5 m wide, and 10 m high. The walls of the chapel are adorned with sculptures representing Biblical scenes. The interior of the chapel is illuminated by chandeliers made of crystalline salt. The underground museum has several sections, showing both the history of salt mining in Poland and the geology of the Wieliczka salt deposit. Each year nearly a million tourists visit the Wieliczka mine, which is one of Poland's top tourist attractions.

In the past few years, some 200 m underground, a sanatorium for patients with bronchial asthma has been established. The microclimate in the chambers left after the extraction of salt produces excellent effects and sensational curing results.

Łężkowice-Siedlec

This deposit has been discovered due to exploration work carried on by the Geological Institute from 1956 to

1960. The deposit is situated about 18 km east of Wieliczka; it is about 3 km long and 400 to 700 m wide. The shallowest occurrence of salt is some 40 m; the deepest one does not exceed 500 m. The internal tectonics of the deposit reveals some main elements:

1. secondary folded syncline built up of the clayey Chodenice beds, formed north of the deposit,
2. folded evaporites in the lower and middle parts of the deposit,
3. the uppermost tectonic element thrust over the upper part of folded evaporites,
4. clayey sediments (Skawina beds) underlying the evaporites, slightly folded under the deposit, and steeply dipping in its southern part.

In vertical profile four cyclothems have been distinguished, comparable with those in other salt deposits. The salt layers in the deposit underwent strong plastic deformation, whereas the clayey-anhydritic sediments were disrupted at places and squeezed out. The original thickness of evaporites was approximately 100 m. Due to later tectonic thickening, in some profiles, the thickness of evaporites exceeds 300 m. In 1968 exploitation began within the western part of this deposit (west of the Raba river), using the method of leaching salt with water through boreholes from the surface (Garlicki, 1962, 1971b).

Moszczenica-Lapczyca

The salt deposit was discovered as a result of prospecting carried on in the years 1964 to 1968. The Moszczenica-Lapczyca deposit is a continuation of the Siedlec deposit eastward, and a connection with the western part of the Bochnia salt deposit has been ascertained. The deposit is about 3 km long and about 500 m wide. Salt layers occur from the depth of 80 to 600 m. The geologic structure of this deposit shows features similar to both the neighboring deposits of Siedlec and Bochnia. The internal structure is very complicated and cannot be mapped on the basis of available boreholes. This deposit has not been exploited, but it should make an important addition to the reserves of the neighboring salt mines (Garlicki, 1970b).

Bochnia

The best description of the Bochnia deposit accompanied by numerous cross-sections and maps one can find is in the monograph by Poborski (1952). In the vicinity of Bochnia, in front of the Carpathians, two Miocene anticlines occur. Cores of these anticlines are built up of flysch sediments which indicates that the evaporites of Bochnia were deposited upon flysch sediments. The salt deposit is situated in an almost vertical northern limb of the northern anticline. The length of the deposit is about 7 km; the width varies from some dozen meters to 200 m. The deepest part of the mine is about 460 m. The inner structural setting of the deposit reveals numerous imbricated folds. In stratigraphic profile four cyclothems can be distinguished which correspond to those of the Łężkowice-Siedlec deposit. The Bochnia salt mine has operated for over 700 years. Presently, the exploitation takes place in the lowermost part of the mine, using the method of leaching salt with water in underground chambers. In the Bochnia salt mine there are numerous artifacts of old mining from the 17th to 19th centuries. Of particular interest are chapels, old chambers and galleries carved out in salt which are situated in the upper part of the mine. Some wooden tools and appliances from Bochnia have become a part of the permanent exhibition in the underground museum at Wieliczka.

Vicinity of Tarnów

On the area situated south of Tarnów (Fig. 4), salt occurs in about a 1 km wide zone in front of the Carpathians. The depth of deposit ranges from 1,000 to 1,600 m; the thickness exceeds 400 m. Salt layers are strongly folded and thrust over one another. The deposit has been recognized only in a few boreholes (Garlicki, 1969, 1970a).

SALT DEPOSITS WITHIN THE AUTOCHTHONOUS UNIT

Rybnik area

In Upper Silesia, in the area situated between the towns of Rybnik and Zory (Fig. 3), salt associated with clayey-anhydritic layers overlies the Carboniferous coal basin sediments. In some profiles, the Miocene sediments are underlain by the Oligocene variegated clays. The salt deposit is about 12 km long and about 7 km wide. Salt layers occur at the depth from 200 m to 300 m. The thickness of the evaporites varies from 50 m to 80 m; the greater thicknesses are observed in the central part of the deposit. The thickest salt layer exceeds 20 m. The deposit is not disturbed tectonically; the layers dip gently toward the center of the basin with dip ranging from 5° to 10° (Garlicki, 1962, 1970a, 1971a).

Wieliczka-Tarnow area

A zone of the autochthonous salt occurrence between Wieliczka and Tarnow (marked on Figure 4 as a chloride facies) is about 50 km long and 1 km to 5 km wide. The depth to the top of salt increases gradually eastward, from about 500 m in the vicinity of Wieliczka to about 1,500 m in the Tarnow area. Thicknesses exceeding 100 m are known from the area situated between Bochnia and Tarnow, where all five cyclothems of evaporites, with thick salt layers, are developed the most completely. This area was probably the central part of the sedimentary basin of the Miocene evaporites (Garlicki, 1968b).

OTHER OCCURRENCES OF THE MIOCENE SALT

An occurrence of the Tortonian evaporites has been found in front of the Carpathian overthrust (Fig. 3), about 20 km east of Tarnow (vicinity of the town of Pilzno). Sediments of the salt-bearing formation which are strongly folded and imbricated occur at a depth of 200 m to 800 m. The salt layers are several meters thick and contain a considerable admixture of clay and anhydrite, however. In the eastern part of the Carpathian foreland, in the area situated south of the town of Przemyśl (Fig. 3), sediments of Lower Miocene occur. These sediments belong to the Aquitanian and are exposed in the narrow zone adjacent to the Carpathian margin. They are developed as salty clays, the thickness of which does not exceed 100 m, without any distinctive salt layers (Garlicki, 1970a).

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