# Geological Prediction of the Mining Feasibility within the Salt Domes of Upper Permian Zechstein, Central Poland

Józef Poborski and Kazimierz Ślizowski
*Academy of Mining and Metallurgy*
*Kraków, Poland*

*ABSTRACT*

*The authors have presented the results of their geological investigations and mining experiences in Zechstein domes in central Poland. As it appears, the domes inner structure is extremely complex and entangled. However, the authors were able to establish certain regularities in that respect, taking into account the stratigraphic column petrophysical bipartition and their tectogenetic pattern. So, the mineable salt deposits mostly occur in the form of secondary diapiric anticlines forcing their way up to the gypsum cap. The larger area of the salt mirror occupied by the anticlines, the more favourable are the mining conditions. In consequence of the fact, comparative halotectonic and morphologic studies of the salt domes group were carried out. Certain functional interdependences have been discovered and graphically presented. On the basis of the diagram it is possible to predict more or less favourable conditions of mining exploitation as well as of localization and establishing of underground storage in the salt domes.*

## INTRODUCTION

This study is based on evidence, presented in earlier papers, concerning the Upper Permian Zechstein in the eastern province of Central Europe (Poborski, 1970, 1974, 1980). At the Fifth Symposium in 1978, the revised version of the lithofacies map of the Zechstein salt basin was presented (Figure 1). At the third and fourth symposia (1969, 1973) the general tectonic conditions of the Polish Zechstein were characterized. In these studies we recognized that the depth to the Zechstein series top in the Kujawy region, central Poland, averaged 5,500 metres, in some places exceeding 6,000 m. That is why the minable zones are connected with the diapiric structures, i.e., true salt domes which are found at shallow depths. Tectogenesis of such domes was the subject of special study. These domes were formed during more than ten halokinetic stages extending from the late Triassic to Quaternary. All these movements are reflected in the pattern of internal structure which can be recognized by subsurface cartographic methods.

Two or three years ago we managed to draw up a halotectonic map of the Zechstein salt basin in Poland at a working scale of 1:500,000. Over 60 salt structures were contoured on the map, some of them being true diapirs. Figure 2 presents a sector of the potash-bearing chloride facies field as seen on the map (Figure 1).

Comparative halotectonic and morphological studies of the salt domes group were carried out and some regularities concerning the inner structure pattern were outlined. At the same time certain structural interdependences were easy to deduce. Consequently, we found a basis to predict the mining geology conditions within the Zechstein salt domes on a regional scale. This problem is the subject of this paper presented at the Sixth International Symposium on Salt.

## REGIONAL DISTINCTNESS OF THE ZECHSTEIN STRATIGRAPHIC COLUMN AND PREDISPOSITIONS FOR HALOTECTONIC PROCESSES

Regional distinctness of the Zechstein series column in the zone of Polish anticlinorium and the adjacent synclinoria was emphasized in the preceding papers and was correlated to the Hanover standard in the North German Lowland. What makes the Zechstein series column distinct is the different lithostratigraphic development of the Zechstein stages Z3 and Z4. Starting in about the middle of the Zechstein Z3 sequence and extending up to the "variegated sandstone" (Buntsandstein), sedimentation took place within a continental environment. Within a continental water regime, thick halitic lutites had formed, i.e.,

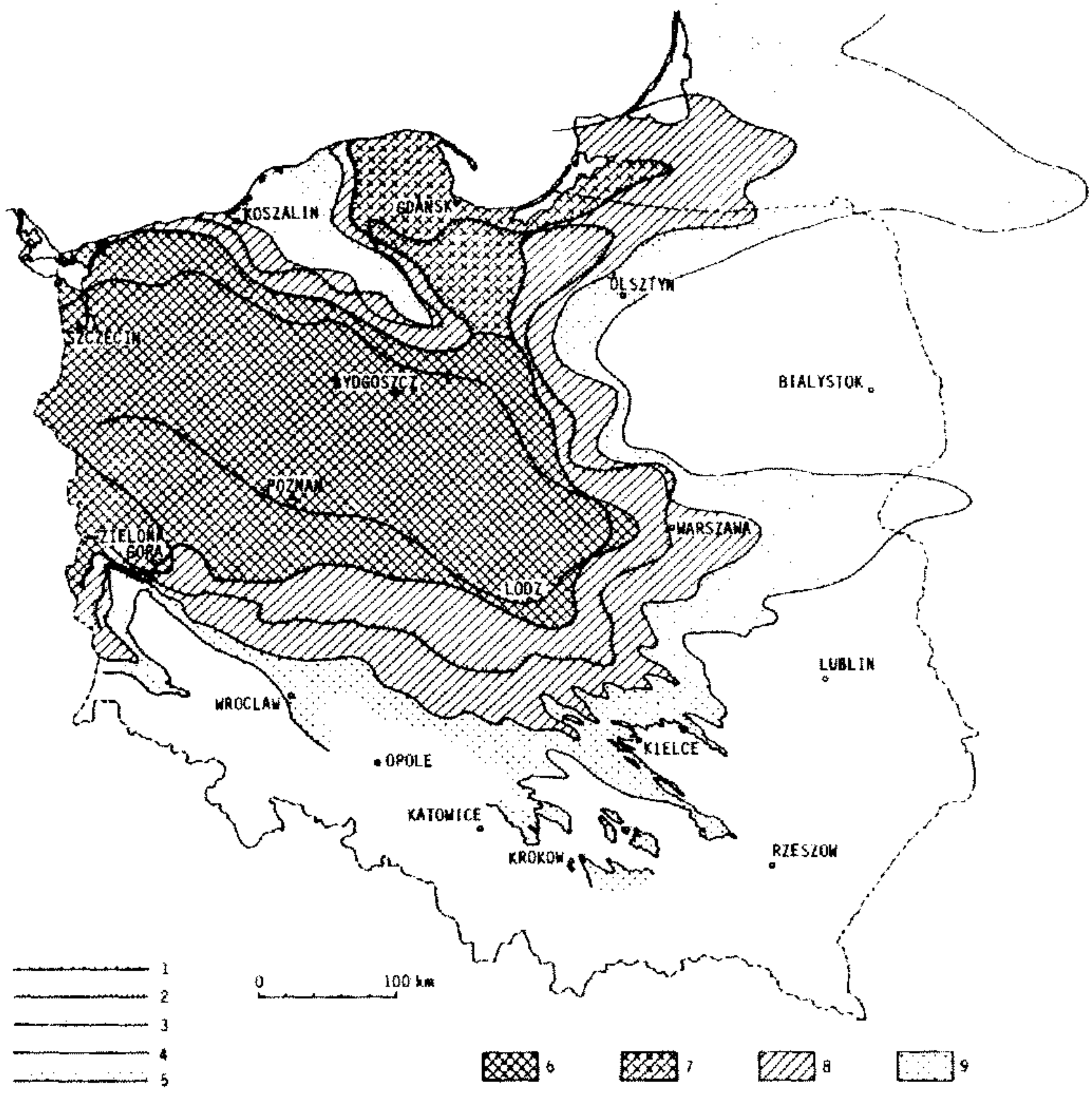


**Figure 1.** General lithofacies map of the Upper Permian Zechstein Series in Poland and Lithuania (USSR). Limit of the chloride facies with Mg-K salts in the upper division of the Zechstein (Z3 + Z4); (2) Limit of the chloride facies with Mg-K salts in the lower division of the Zechstein (Z1 + Z2); (3) Limit of the chloride facies (without Mg-K salts) in the upper division of the Zechstein (Z3 + Z4); (4) Limit of the chloride facies (without Mg-K salts) in the lower division of the Zechstein (Z1 + Z2); (5) Limit of peripheral facies (sulfate-carbonate, littoral facies); (6 and 7) Chloride (rock salt) facies which is potassium-bearing; (8) Chloride (rock salt) facies without potassium salts; (9) The peripheral, littoral, carbonate-sulphate facies.

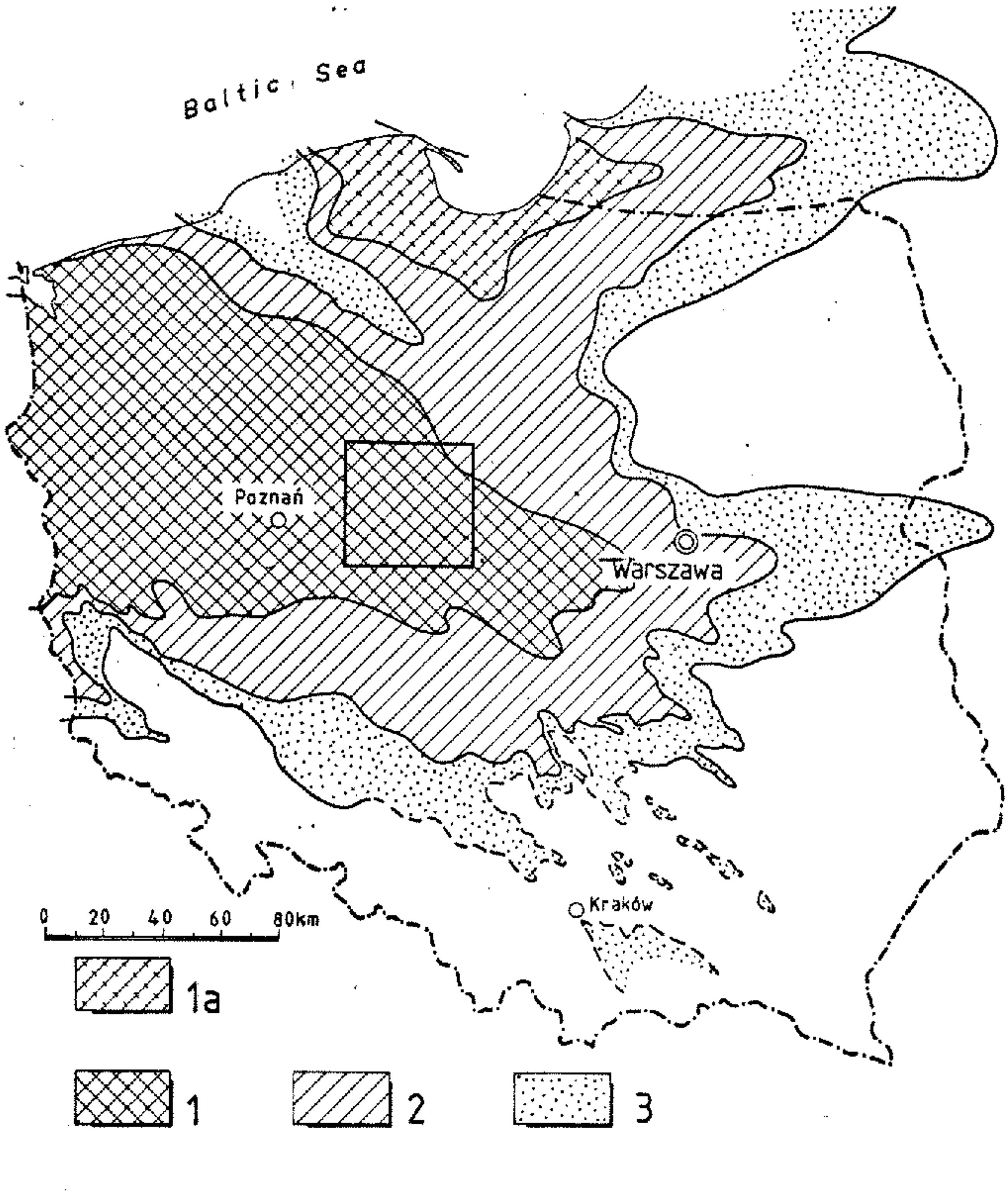


Figure 1. Sketch lithofacies map of Zechstein basin in Poland. 1, field of chloride facies /rock salt/ with Mg and K salts; 1a, field of chloride facies with Mg-K salts mostly destroyed by karst processes; 2, field of chloride facies /rock salt/ without Mg-K salts; 3, peripheral zone of sulphate-carbonate-littoral facies

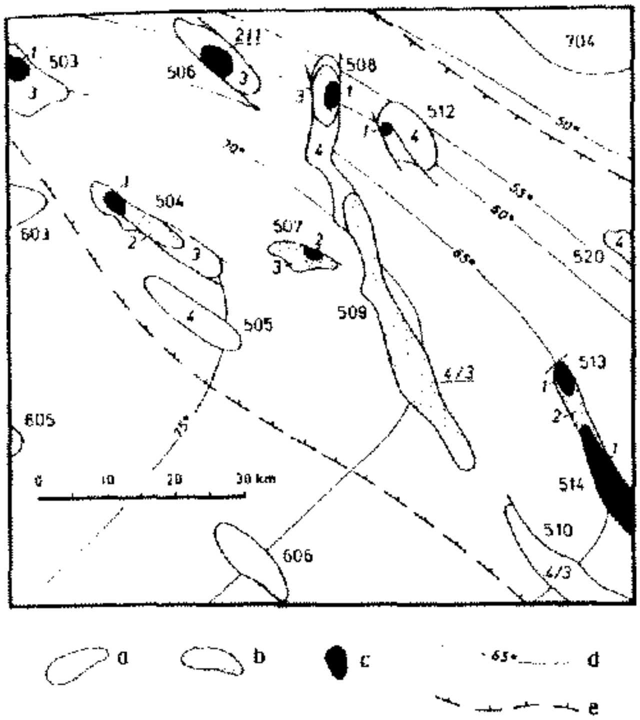


**Figure 2.** A sector of the Zechstein basin halotectonic map as seen in Fig. 1: a, anticline structures (salt swellings); b, salt structures piercing upward partly across Mesozoic cover; c, salt domes (piercing fully); d, geoisotherms at the depth of 2,000 m; e, boundaries of the salt structures group in the region of central Poland.

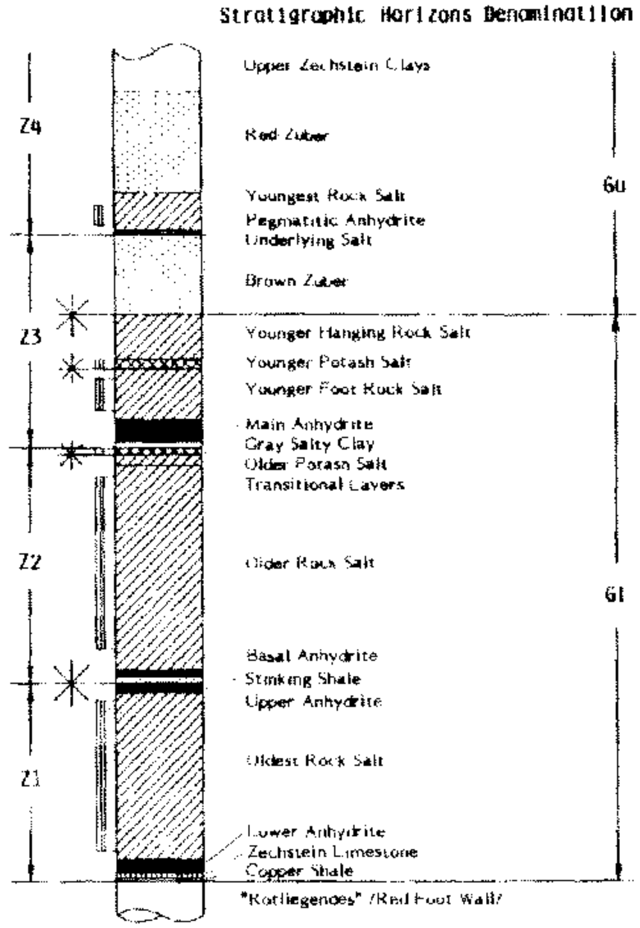


**Figure 3.** Zechstein stratigraphic column in the region of central Poland, petrophysical bipartition (Gl and Gu) and predispositions for structural subdivision as well as mineable salts having been marked.

so-called zubers (Haselgebirge), brown zuber (Z3) and red zuber (Z4). That is why a petrophysical bipartition of the whole Zechstein column is strongly marked. This is why the sedimentary column can be divided into two contrasting segments from the point of view of rock mechanics (Figure 3):

1. a lower segment (Gl) comprising stages Z1, Z2 and lower part of the stage Z3 where thick massive chlorides predominate; and
2. an upper segment (Gu) consisting of the upper part of the stage Z3 as well as of the whole stage Z4 with its prevailing salty clays.

Such a lithological and petrophysical bipartition must necessarily be reflected in the tectonic processes.

Rocks of the lower segment of the column (Gl) were continuously mobil owing to the potential plasticity of the chloride rocks. The upper segment (Gu), on the other hand, gives evidence of the opposite behaviour, as the clayey rocks remained passive, inflexible and easily crushed and brecciated.

Reviewing the petrological succession in detail in this Zechstein column, attention was paid to some stratigraphic horizons where these different rock members were in contact. By this we mean the contrasting petrophysical properties of one member against another. Such horizons were predisposed to the development of dislocation planes during structural development of the salt domes. These were clearly indicated at the column edge by eight-branched stars (Figure 3).

## THE MAIN FEATURES OF THE SALT DOMES' INNER TECTONICS

The salt domes are sometimes considered monolithic massives of rock salt, including some intercalations. In fact, they are built of the whole sequence of the salt series strata. The most striking features of the internal tectonics within the Zechstein salt domes may be mentioned as follows:

1. Intense and very steep folding of the layers, with a very high wave amplitude when compared with the wave length (Figure 4a)

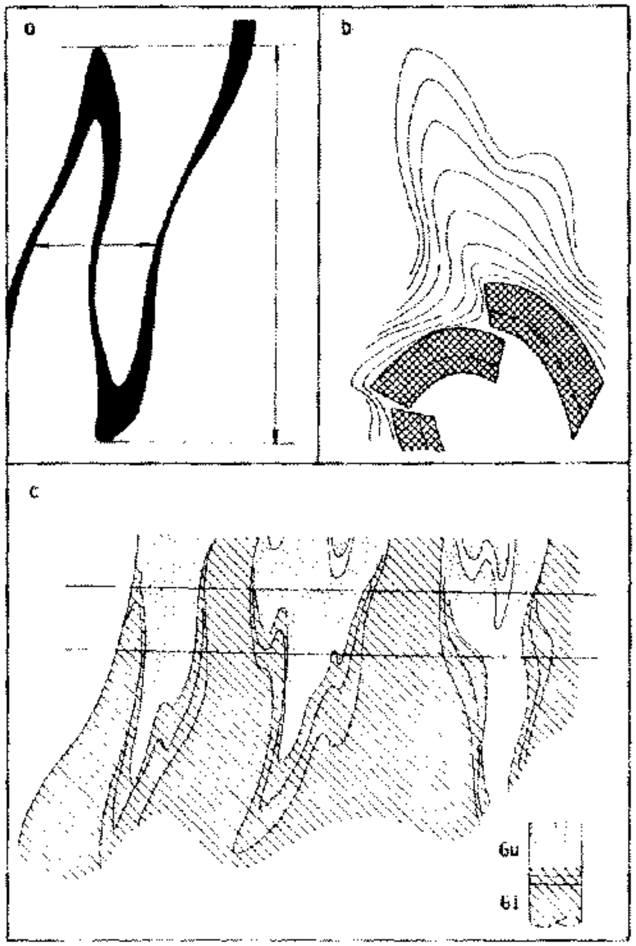


**Figure 4.** Some striking features of the salt domes inner structure as explained in the text.

## THE INTERNAL STRUCTURE PATTERN OF THE SALT DOMES

A general pattern of the internal structure may be briefly outlined, taking into consideration halotectonic phenomena.

First, and most important, is the mutual contrasting mechanical behaviour of the two Zechstein column segments (Figure 3), denominated as the lower one (Gl) opposed to the upper one (Gu). During halokinetic folding the concentrated chloride strata of the lower segment (Gl) form the anticlines piercing upward through the overlying strata of the upper segment (Gu), as shown in the Figure 4c. So, secondary diapiric domes occur within the single main salt dome.

Let us pay attention to the hard and stiff strata subdividing the lower column segment (Gl), i.e., "upper anhydrite" (Z1), "the stinking shale" and "basal anhydrite" (Z2), which are underlain and overlain by very thick rock salt successions. We recognize that these strata were rigid and resisted the structural doming. In the majority of the Zechstein salt domes, which are circular or oval shaped, those strata were uparched although intersected and partly dislocated. From such a barrel-like vault the older rock salt massif was strongly deformed, thus forming two or three very high digitation anticlines (Figure 4c and 5).

Subsurface geological methods as well as geophysical ones help us to reconstruct the inner structure pattern of the salt domes taken as a whole in their height. The general sketch pattern is roughly outlined in Figure 5. There, three structural stages have been revealed, each being graphically marked and explained.

Let us consider the uparched and dislocated top of the

2. Quasi-plastic thickening of the salt fold bends (Figure 4a)
3. Contrasting mechanical relation of the salt layers to the adjoining barren rock (anhydrite, dolomitic marl, shale); the best example being observed at the contact with a thick anhydrite stratum where quasi-plastic bulging of the layered salt against a sharp anhydrite bend is a typical phenomenon (Figure 4b)
4. The anticline cores built of the older salts pierce upward across the overlying younger evaporite sequence; for this reason, several diapiric structures are to be surveyed (Figure 4c)
5. A common structural phenomenon observed within the anticlinal limbs. Certain stratigraphic chloride members are very much thinned from their normal thickness. At the same time the intercalating barren strata are torn up and squeezed as well as pinched completely out, the remaining joints marking their way upward.

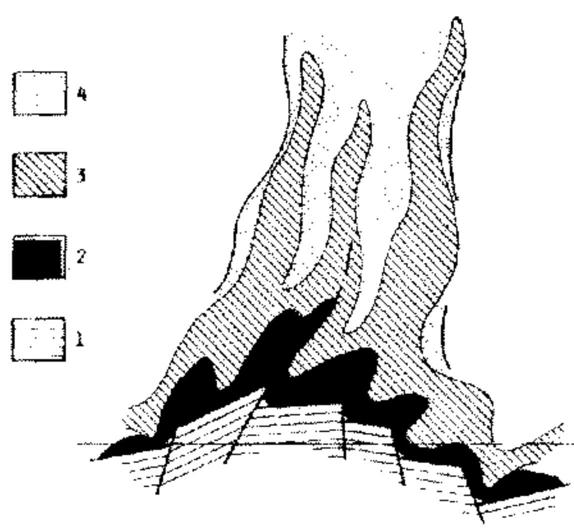


**Figure 5.** General sketch pattern of the salt dome inner tectonics. 1, Zechstein substratum ("Rotliegendes"); 2, 3, 4, the first, second and third structural stages.

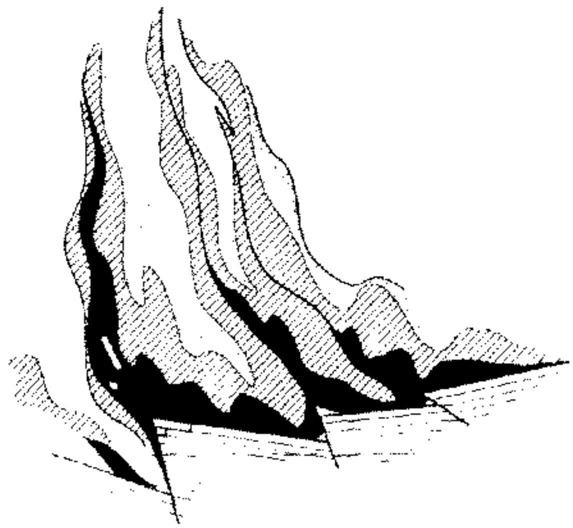

**Figure 6.** The inner tectonics pattern of the very elongated Zechstein salt dome. 1, Zechstein substratum ("Rotliegendes"); 2, 3, 4, the first, second and third structural stages.

lowest structural stage (Figure 5). Some modifications of the described structural pattern have been demonstrated, depending on the tectonic scheme in the deep substratum as developed by epeirogenic movements and subsequent kind of faulting. For instance, such a structural variation is suggested as shown in Figure 6. It is deduced in the event of very elongated salt domes running parallel to the major structural trends, that dislocation zones exist in the deep substratum. A good example of this feature is the Klodawa dome, its tectogenesis having been described in the paper presented at the Fourth Symposium on Salt. There we note reverse faulting and thrusting of the lowest salts (Z1) upon the older ones (Z2) is the case in the early halokinetic period.

## STRUCTURAL POSITION OF THE REAL SALT DEPOSITS

The economically useful salt layers of the Zechstein series have been marked at the margin of the stratigraphic column (Figure 3). So, their stratigraphic position is known with tolerable accuracy, depending on the quality and uses of the mine product. These are magnesium and potassium salts, here termed "potash salts," as well as pure rock salt.

Following the internal structure outline, the main rock salt deposits develop during the second structural stage (Figure 5) and they are represented by the enormous concentration of the older rock salt (Z2) in the anticline cores of the first order (Figure 4c). On the other hand, the older potash salt (Z2), as well as the younger one, together with the underlying younger rock salt (Z3), occur in the anticline limbs, thus forming layered deposits, even there partly deformed. Moreover, the younger potash (Z3) concentrates within the second order fold bends (Figure 4c).

In the third structural stage the youngest and purest rock salt (Z4) forms some mineable concentrations within the syncline bends.

## THE LIMITED MINING FEASIBILITY

The principles of the traditional underground mining are the same, regardless of the mineral raw material. Specific exploitation methods are related, however, to the solubility of the prevailing salt rocks. That is why solution mining methods developed, thus broadening the exploitation possibilities.

As noted in the halotectonic map (Figure 2) we considered the mining exploitation feasibility as limited by the depth of occurrence and the geothermal grade. Both criteria were adopted to the maximum depth reached by the well solution mining, i.e., about 2,200 m (−2,000 m below sea level). The depth of the traditional shaft mining is limited as well to 1,200 m (−1,000 m b.s.l.), based on knowledge obtained from previous European salt mining experiences.

Moreover, feasibility of the underground salt mining has proved to be dependent on the natural conditions: 1) geodynamic, 2) hydrogeological, and 3) the occurrence of gases. Hence, the corresponding menaces in the salt mines have to be addressed.

The precaution against water that might break into the shaft from the surrounding rocks is really the most important factor in the mine design and exploitation of salt deposits. Protection against a water menace of this kind is usually undertaken by safety shelves and pillars made of the uniform rock salt surrounding the exploitation spaces (Figure 7). In such a case the salt miner has to work like a diver closed in a caisson on the bottom of the sea. He doesn't worry about the quantity or hydrostatic pressure of the surrounding water. However, he has to take great care with the water-tightness (imperviousness) and mechanical resistance of the caisson walls.

## MINEABLE SALT DEPOSITS AND THE MINE LOCALIZATION IN THE SALT DOMES

Considering the inner structure pattern, it might be asked what are the space considerations of the mineable salt deposits and the mine block limits within a Zechstein salt dome in the cited geological region. The answer may be obtained in the following stereometric terms.

The depth to the salt dome mirror ranges from 120 to 470 m, in general, enlarging according to the horizontal size of the dome. Customary thickness of the safety shelf underlying the salt mirror averages 200 m. The side pillars left along the dome walls are at least 50 m thick (Figure 7).

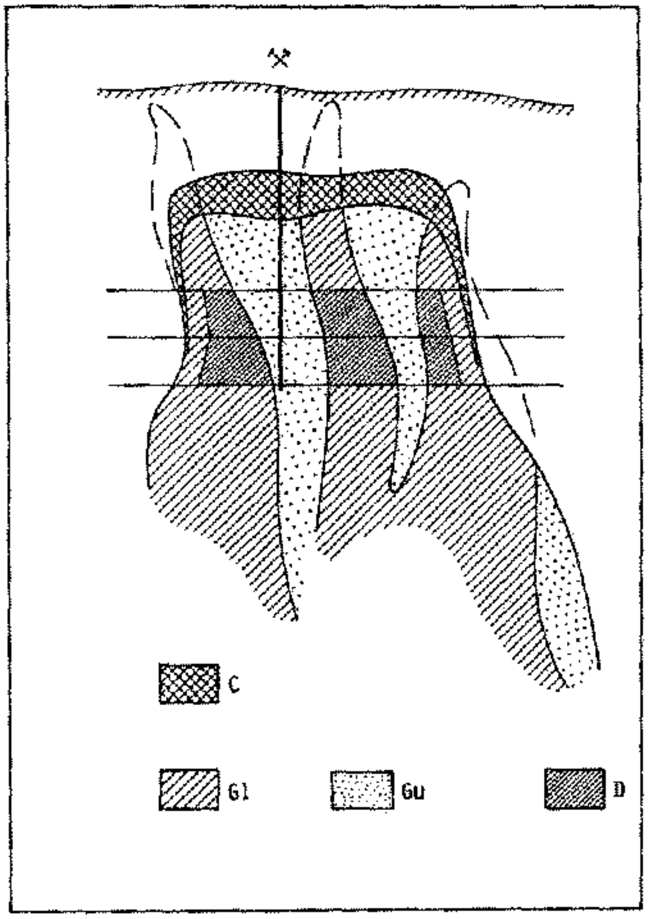


**Figure 7.** Mineable blocks within the exploited salt dome. Gl, a lower Zechstein column segment; Gu, an upper column segment; D, mineable blocks; C, gypsum cap.

The vertical span of the mine levels, i.e., between the uppermost (first) and the lowest one, usually doesn't exceed the first order folding amplitude as seen in Figure 7. There the diapiric anticlines of the lower Zechstein segment (Gl) have been shown outcropping above the salt mirror, their limbs dipping very steeply. Thereby, the area taken up on this flattened surface by the anticline massives is approximate to that on the first mine level. That is why those anticline areas may be assumed nearly equal to our stereometric calculations.

The larger the anticlined area on the salt mirror and the more closed they are, the more favourable the prediction for the mining conditions becomes.

## THE ADOPTED COMPARATIVE STUDY METHODS

The preceding considerations may be summed up by the following statement: the most determinant agent for - mining feasibility prognosis appears in the area relation. It can be expressed in geometric terms, i.e., ratio A/P, P being equal A + S where

P = the salt dome area measured on the salt mirror,
A = the anticlinal form area on the mirror,
S = the synclinal form area on the mirror.

Some morphological comparative studies on this salt dome group in the region were carried out. The problems in question were put in the following order:

1. What morphological parameters should be competent and compared
2. How to make easy the provisional cartographic reconstruction of the A/P ratio
3. How to forecast the A/P ratio on the given dome not exploited as yet.

The following parameters were considered:

l = dome length measured on the salt mirror,
w = dome width measured as above,
c = geometric dome class determined by the relation w/l, at the same time denominating: $c_1 > 0.5$, $c_2 = 0.5 - 0.25$, $c_3 < 0.25$,
h = salt dome height measured from the average depth of the saltbearing formation,
d = salt mirror depth,
z = regional halotectonic coefficient expressing the dome form variability as the depth is growing.

The A/P ratio determination was made easier by the reconstruction of the salt mirror geological map. On that score the following phenomena have been the keynotes:

1. The line delimiting A and S areas on the mirror surface is an intersection line between the lower Zechstein log segment (Gl) and upper one (Gu) as well.
2. The Gl segment outcrops are typically covered by a sulfate cap, mostly being anhydritic, whereas the Gu segment outcrops are usually represented by weathered gypsiferous clays.
3. Some details of the salt mirror topography may be explained in this fashion—the positive forms, i.e., elevations are corresponding to Gu segment, while the negative ones (basins and valleys) to the Gl one.
4. Considering the inner structure pattern of the salt dome as well as its halotectonic coefficient, we feel it is reasonable to transfer the geological situation from the first mine level to the salt mirror surface. On unexploited domes, however, such a cartographic picture can be provisionally reconstructed by means of shallow prospecting wells.

The exploited Inowroclaw dome may serve as a good example of the geologically surveyed salt mirror (Figure 8). There delimitation of the anticlinal and synclinal forms could readily be determined.

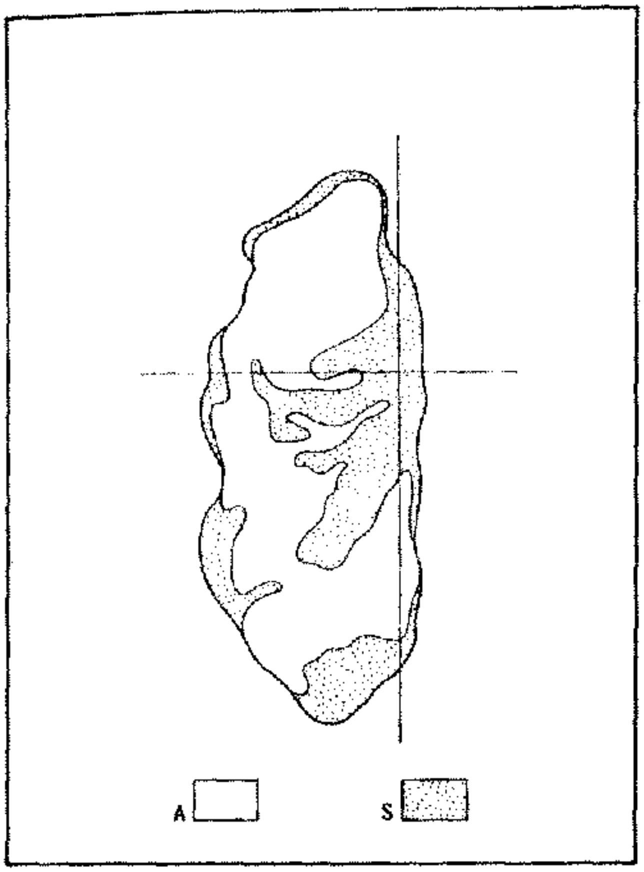


**Figure 8.** Salt mirror on the Inowrocaw salt dome. A, anticline forms; S, syncline forms.

## THE RESULTING DIAGRAM

A group of 11 Zechstein domes in the considered region were investigated, the A/P ratio having been determined for each one by planimetric surveying on the salt mirror. This ratio will change with increasing depth in a dome according to the halotectonic coefficient "z". The last factor comprises the dimensions of the fold wave amplitude.

Geological parameters for the salt dome groups have been listed and thus confronted in the table below.

| Salt Dome Designation | l km | w km | w/l class | d m | P $km^2$ | A $km^2$ | A/P $km^2$ |
|---|---|---|---|---|---|---|---|
| 502 | 0.7 | 0.4 | $c_1$ | 170 | 0.30 | 0.27 | 0.89 |
| 610 | 0.8 | 0.5 | $c_1$ | 190 | 0.50 | 0.44 | 0.88 |
| 512 | 1.0 | 1.0 | $c_1$ | 120 | 1.00 | 0.74 | 0.74 |
| 508 | 2.5 | 0.8 | $c_2$ | 150 | 2.00 | 1.28 | 0.64 |
| 513 | 5.0 | 1.5 | $c_2$ | 390 | 4.00 | 2.24 | 0.56 |
| 521 | 3.2 | 2.2 | $c_1$ | 320 | 5.90 | 3.00 | 0.51 |
| 504 | 5.5 | 1.7 | $c_3$ | 250 | 8.50 | 3.57 | 0.42 |
| 522 | 3.7 | 3.3 | $c_1$ | 250 | 9.50 | 4.37 | 0.46 |
| 503 | 5.5 | 3.5 | $c_1$ | 470 | 16.50 | 6.06 | 0.40 |
| 518 | 6.7 | 4.1 | $c_1$ | 370 | 21.00 | 7.89 | 0.38 |
| 514 | 25.0 | 1.5 | $c_3$ | 230 | 37.50 | 12.37 | 0.33 |

The resultant A/P ratio in the table is a function of parameters: P, h, c, z. Parameter "h" in the region is known to range from 5,000 to 7,000 m, while coefficient "z" remains almost the same, i.e., nearly constant. The parameter "c", however, might be provisionally neglected as being involved in the planimetric calculations on the salt

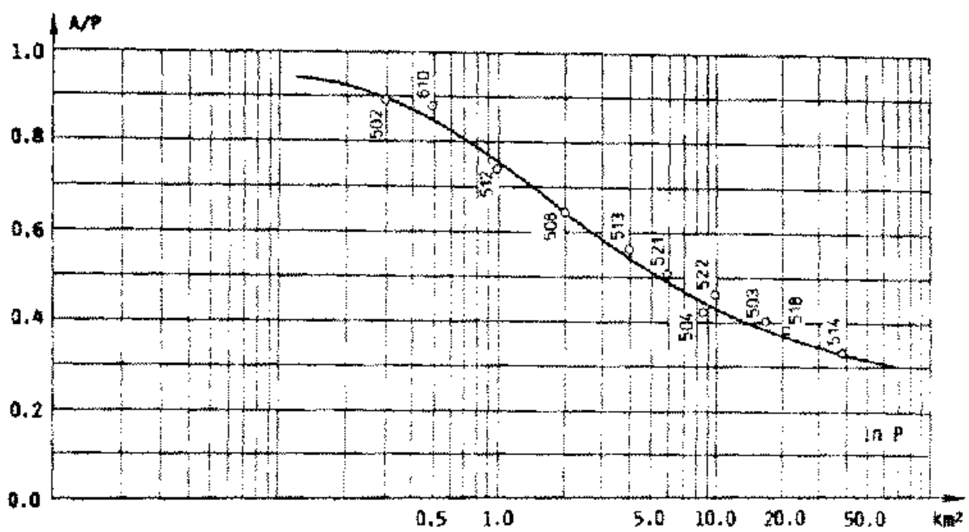


**Figure 9.** The A/P function diagram as explained in the text.

mirror. Consequently, the A/P ratio can be expressed as the argument function of "P" area: A/P = f/P.

Based on the data listed in the table, a diagram was drawn, thus illustrating the functional dependence of the A/P ratio on the "P" values. These have been plotted on the horizontal (abscissas) axis on a logarithmic scale in order to shorten the diagram as well as to make it more perspicuous.

## THE DIAGRAM INTERPRETATION AND SUMMARY

We have attempted to theorize on the problem of the inner tectonics of salt domes for mining purposes. That is why the structural form units must be simplified by some stereometric assumptions. At the same time the morphologic class parameter "c" is meanwhile omitted. As a result the curve of the A/P function is outlined, thus reflecting a regional halotectonic trait that is common for the whole salt dome group. The diagram may be interpreted as follows:

The A/P ratio appears to be inversely proportional to the "P" value, the dependence not being straightforward. The resulting curve could be expressed rather by a third degree equation.

The greater "P" value the smaller in size the anticline form area on the salt mirror, as well as at any mine level. Therefore, the greatest A/P ratio are revealed by the smallest domes, which belong mostly to the class "$c_1$" when $w/l > 1/2$. They are circular or broadly oval-shaped. Conversely, the largest domes have shown the smallest "A" area, their shape parameter being of the "$c_3$" class, i.e., mostly $w/l < 1/8$. On the other hand, the domes of medium size /9–21 $km^2$/ belong to the "$c_2$" or "$c_1$" class, the last ones having the greater A/P ratio.

From the theoretical considerations evolved above some practical conclusions might be deduced. The greater the A/P ratio the better the mining prospects. In general, the medium-sized domes of the "$c_1$" morphological class have proved most promising.

In the determined regions of the Zechstein salt basin we have tried to take advantage of the cited conclusions. The A/P ratio diagram appears useful in the salt industry practice in relation to all parameters of the mining works, i.e., prospecting, reserve evaluation, mine designing, especially the shaft and the well localization for solution mining or underground storage.

## REFERENCES

Poborski, J. W. 1970. The Upper Permian Zechstein in the eastern province of Central Europe, *in* Rau, J. L. and L. F. Dellwig, *eds.*, Third Symposium on Salt: Northern Ohio Geological Society, Inc., Cleveland, pp. 24–29.

Poborski, J. W. 1974. On the tectogenesis of some diapiric salt structures in Central Poland, Upper Permian, *in* Coogan, A. H., *ed.*, Fourth Symposium on Salt: Northern Ohio Geological Society, Inc., Cleveland, pp. 267–270.

Porborski, J. W. 1980. Discontinuity in Upper Permian (Zechstein) succession of evaporites in eastern Pomerania, Poland, *in* Coogan, A. H. and Lucas Hauber, *eds.*, Fifth Symposium on Salt: Northern Ohio Geological Society, Inc., Cleveland, pp. 153–158.