World Reserves of Mineable Potash Salts Based on Structural Analysis

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ABSTRACT

After definition of terms about the categories and classes of mineral reserves and the mineability, the paper will demonstrate the criteria of evaluation, such as data about thickness, area, depth and grade, also degree of inhomogenity, primary or secondary changes of mineral facies, type of deformation and strength recognizable on mineralization and fabric. In addition, the stratigraphy and the configuration of the salt bodies dealt with and, finally, the physical properties of the framing overlying clastics, hydrogeology included.

Hence, result reductions of the reserves in place, besides those caused by stress-control, barrier-pillars, etc. From this standpoint, the paper deals with all relevant potash deposits from Williston Basin and New Mexico to New Brunswick, Carmopolis (Brazil), Point Noir (Congo), The Tertiary of Sicily, Spain and Elsass, to the Zechstein, the Donbass-Graben and Solikamsk-Beresniki with characteristic drawings.

A summary of my calculations is given by a table at the end of this paper which is correlated with the subdivided world reserves of Ivanov and Voronova (1975).

Two other pictures show the world potash reserves by their geographical distribution according to the figures of Kruger (1973), Ivanoff (1969) and Mühlberg (1963) with 129 billion metric tons and my calculation of about 520 billion tons K_2O in situ and 37 billion tons K_2O mineable.

Finally, a partly fictitious graph illustrates the very different lifetime of the mined deposits of the potash producing countries.

INTRODUCTION

Inexact delimitations of terms lead to some misunderstandings and errors in the estimation of the worlds reserves of potash.

Some Definitions and Limitations

We consider a *mineral occurrence* to be a *mineral deposit*, if the concentration of productive minerals and the size of the ore body are sufficient for mining. Then we distinguish between "in-place", "recoverable" and "mineable" reserves of a mineral deposit, and these terms are defined as follows:

- "In-place, or *in situ*," stock is the sum of all productive mineral constituents in a deposit
- "Recoverable" stocks are those reserves that can be extracted in view of the present technical capabilities, without stringent regard to economics
- "Mineable" stocks are recoverable reserves only, if the expectation is reasonably established that the sum of all costs for extraction and ore-dressing, the capital costs and a proportionate profit are included and can be recovered over a certain minimum production period.

The last definition is valid at least for the Western World. The mineability depends not only on the properties of the deposit, but on infrastructural conditions, the availability of energy, water, skilled labour, the climate and distance to the centers of demand, and, finally, on the attainable price.

Certainly the mineable reserves, discussed later, are not based on special feasibility studies but on geological and geographic-economical comparisons with already operating mines in the various types of deposits.

"Geological" or "prognostic" reserves are often based on rather generous assumptions and are not the object of this consideration.

When dealing with the East European deposits it must be mentioned that the Russians stringently define reserve categories as A, B, C_1 and C_2, which correspond approximately with our terms "secure," "probable" and "possible" and not that accurately with the terms "proven" and "inferred."

Further in this discourse only productive potash ores are dealt with, such as sylvinite, langbeinitite and kainite, and are always expressed in K_2O equivalents.

Carnallitite generally cannot be regarded as productive potash ore because of the insurmountable problems in removing large quantities of $MgCl_2$ brines.*

One confusing fact should be pointed out at the start: potash reserves are described in tons and are frequently cited without mentioning whether they are in-place, mineable, chloride or sulphate, ore, KCl or K_2O, short tons or metric tons. A worldwide convention should be introduced to release only the mineralogical characteristics, K_2O grade if available—and metric tons of K_2O equivalent.

The structural analysis—in the sense of the title of this paper—involves stratigraphical position, tectonic dislocations or deformations, and also mineral—facial constancy or changes and secondary alterations in the potash beds.

The determination of extraction rates is a question requiring special information, or if estimated, depends on depth, strength of the rock-salt, i.e., grain size and fabric, the properties of the overburden rocks and the configuration of the ore body, and is based then on analogies to known deposits.

Finally, as a matter of course, the degree of accuracy on reserve calculations changes within the frame of necessary and available data about volumes and average contents. The degree of approximation to the reality cannot be the same in all cases.

SOME MODELS OF LITHOFACIES AND STRUCTURES

Some typical examples of lithofacies and structures should illustrate rather at a glance, the points of view in approaching the problem. With a series of pictures and short comments, more detailed descriptions can be avoided later.

The shadowed curve in Figure 1 shows the K_2O contents of Z-2 Hartsalz, the other step-curve the $MgSO_4$ content. The tendency of decreasing K_2O and increasing kieserite shows a primary facies change with "reciprocal" sharing of two paragenetic minerals.

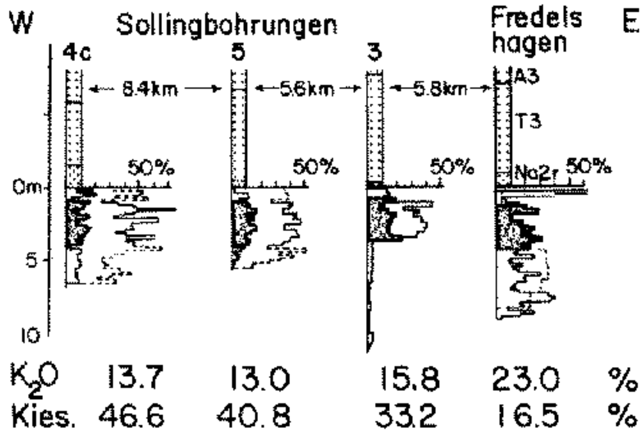


Figure 1. Nord-Solling exploration, West Germany.

Figure 2 shows isolines of K_2O with a decreasing trend toward the northwest edges of the Upper-Werra-Hartsalz, without changing of paragenetic sulphates.

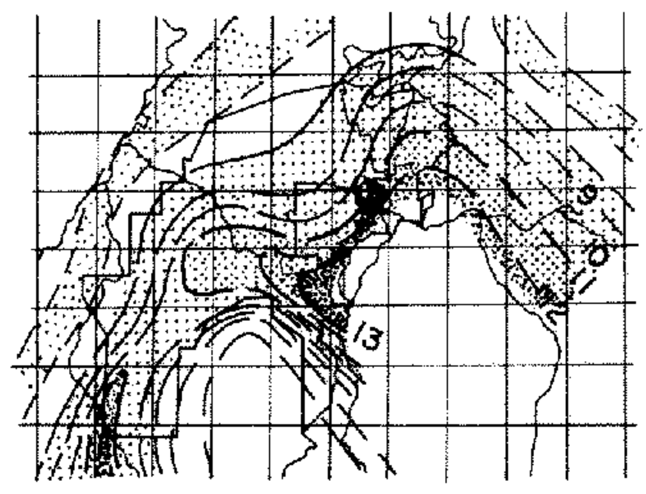


Figure 2. Hattorf Mine, Phillipstal, West Germany.

In Figure 3, light grey represents windows into continuously underlying Hartsalz, the dark grey is carnallitite immediately above the Hartsalz, and the circular structures are salt-filled volcanic pipes with metamorphic haloes. In spite of the patchy appearance, the layer reveals, statistically, a high degree of homogeneity over relevant distances in the Werra district.

*The commonly mentioned carnallitite processing plants in Germany and in Solikamsk (USSR) are rare exceptions, because up till now one could get rid of the Mg Cl brines in Salzdetfurth by cost-covering sales to Norway. In the Werra District these brines are disposed of by injection into a dolomitic strata of the Upper Zechstein. The goal in West Germany is and was only the improvement of the K_2O grade and not the Mg. In the Werra district, the carnallite share of the rough ore is in one case 10%, in the other 17% and in Salzdetfurt 35%.

Figure 3. Wintershall Mine, Heringen, West Germany.

The question will always arise how extensive an extrapolation into the less known area may be drawn. Constancy or recognisable trends help to delineate a mineable area.

In Lanigan (Figure 4), the collapses are caused by fossil dissolution of the 10-m deeper, former carnallitic zone which affected even the uppermost sylvinitic zone (3) and led to an inflexion of the second Red Bed. These secondary disturbances extend somewhat into the "Dawson Bay" and cause a loss of about 10% in this field.

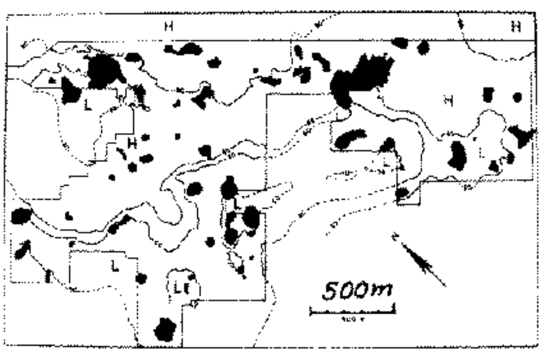


Figure 4. Lanigan Mine, Sask., Canada: Chaotic distribution of break-ins.

Barren parts, though of an entirely different origin, in Balsareny (Catalan Basin) amount to 25% according to Rio Tinto—Potash Branch. Local thinnings in the Fulda district lead to losses of more than 15%. There is no known occurrence of in-tact and entirely regular potash beds even in tectonically calm regions.

This Hannoverian diapir (Figure 5), one of the most unexpected structures in Germany, shows a very great halofluidal whirl. The older rocksalt of the Z 2 mantles the younger Z 3, and Z 3 the youngest Z 4. In this and other cases of that kind, the underground exploration can only proceed step by step over decades through methodical and permanent work of specialised mining geologists. Reserves can be calculated mostly up to a C_1 class in an advanced development stage, if current mapping, well-aimed horizontal and inclined underground drillings and geophysics have been performed properly.

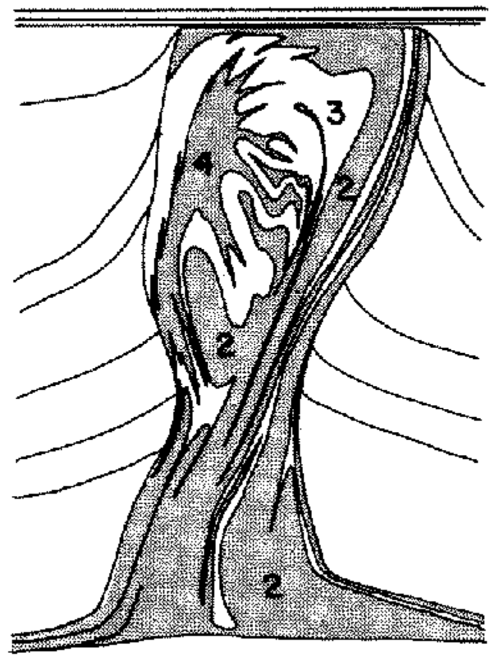


Figure 5. Mariaglück Mine, Salt-plug of Höfer, West Germany. The basis is about 5,000 m below surface.

The diapir of Cardona of the Eocene Catalanean Basin (Figure 6), with its "cock-comb" shape (sylvinite is black), is a quite different halofluidal type than the hannoverean salt plugs, due to other initial conditions, such as the original salt thickness, depth, composition and tectonic forces.

In both cases, an estimation of reserves in a pre-mining

Figure 6. Salt plug of Cardona, after J. Montoriol-Pons.

stage is practically impossible. However, if such a plug is situated within the habitat of a potash sequence, with positive characteristics, and based on the results of a rather tight grid of drilling into the structure, a statement on probabilities could be made.

In Figure 7, grey is carnallitite and black is kainite. It shows deformation by compression in a clastic framework which has nearly the same plasticity as the salt body. In the various subbasins of the saliferous Miocene in Sicily there also are very dense, folded salt structures up to "pseudo diapirs." The potash beds are scattered, and only vague reserve figures can be quoted.

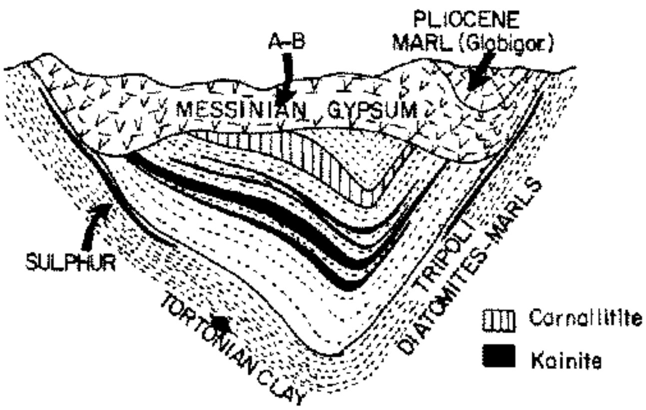


Figure 7. S. Cataldo-Palo, Sicily, after S. Adamo & L. Ramberti (1975).

The shown models naturally, represent only a small selection of facies and structural appearances. In spite of the possibility of classifying salt deposits into some structural and mineral paragenetic types, each one also shows distinct individual features.

In the following sections, the three greatest known potash deposits, in Saskatchewan, in the Upper Kama region, and in the Pripiat depression, will be dealt with more thoroughly than those mentioned later, in order to substantiate the reserve figures that have been altered considerably in comparison to earlier statistics.

SASKATCHEWAN SUBBASIN, CANADA

The areal figures shown in the table below result from a planimetrical survey of the sylvinitic portions of the 3 Potash zones according to M. Holter (1968, 1969). See Figure 8. The medium thicknesses and K_2O contents are taken from his isopach and KCl grade maps. It may be mentioned that we can distinguish 4 potash zones within the Lanigan area: (1) Esterhazy Member, (2) Belle Plaine M and (3) the locally mined member, which is separated by a 3-meter rocksalt bank from seam #4, the Patience Lake Member. The upper section of layer 3 (2.8–3.4 m) regularly contained 28% K_2O and more. Member 2 (Belle

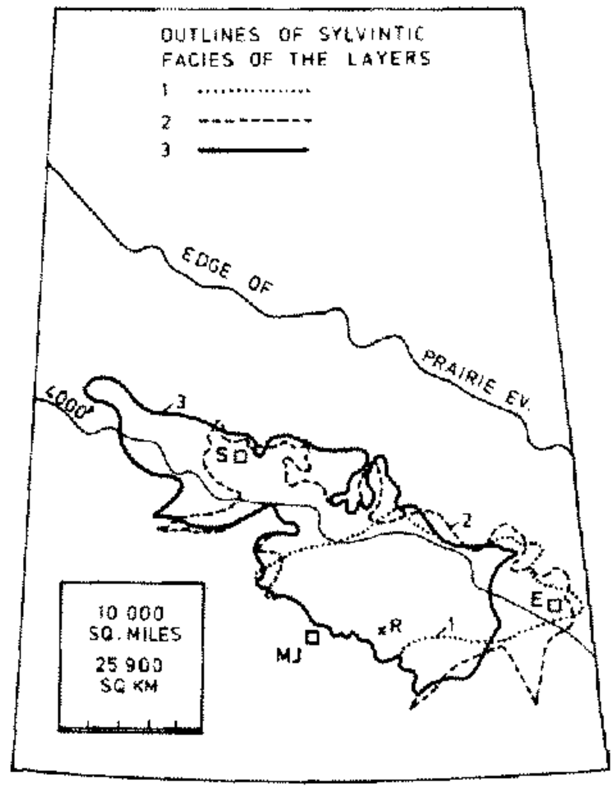


Figure 8. According to M. Holter, 1968.

TABLE 1

	Mill. m^2	Avg. Thick. m	Mill. m^3	Avg. sp. gr.	Million metric tons	Avg. % K_2O	Billions metric T K_2O
Zone 3	55372	12	664464	2.14	1421953	16	227,512
Zone 2	53160	7	372120	2.14	796337	17	135,377
Zone 1	35827	12	421524	2.14	902061	16	144,330
		31	1458108		3120351		507,218 *in situ*

Plaine M) is at this place very frequently carnallitic and exceeds scarcely 10% K_2O.

All in all, M. Holter's outlines and grades are certainly quite conservative and beyond question. The sylvinitic areas of the three zones cover, within their joint maximum periphery, 67,702 km², from which the value of 7.49 million T K_2O per sq km can be calculated.

In Saskatchewan, all reserve calculations were based upon a depth limit of 3500 feet (1067 m), in accordance with current convention. The stress increase in 4000 feet (1219 m) is 12.46%. That seems bearable in view of the assumed low, long-term extraction rate and the expected moderate temperature, even when unfavourable grain size and fabric in the prairies and the thinness of the salt roof are taken into account.*

*A west German potash mine (diapir) presently operates at a 1400-meter level (4593 feet), although under different structural conditions.

The following reductions of areas are taken:

1. Protection of human settlements, water reservations, road, railway and airport allowances totalling all together 10%
2. Pillars left over for faulted or irregular, steep inclined parts, salt horses, or intraformational collapse-structures within the potash sequence, break-ins of the lower overlying clastics, brine areas, and carnallitic islands* about 20%
3. Suberosional areas (according to Gorell and Alderman, 1968). The areal measurements of the dissolved indentations in the "Last Mountain Lake square" showed a loss of 16.18%. Amazingly, there were no extended channels to the south and southeast solution border following the general dip, but deep isolated troughs—dolines—with apparently deep Karst drainages. The distribution makes it rather difficult to regard these kinds of break-ins as certainly big, but isolated phenomena. From north to south, 5–15%
4. Poor grades—lower than 16%, 10–20%.

It is assumed that only one mining cut with a medium height of workings of 3 meters can be made and that there is the possibility of changing the zones as circumstances necessitate. The total extent of the three zones projected onto one plan, assuming a 4000-foot (1219 m) depth limit, amounts to 3214 sq km × 0.9 (a) × 0.8 (b) × 0.95 (c — NE range) × 0.85 (d) about 19,000 sq km remain.

Under the conditions of stress release and control systems, including large barriers between mining fields, an overall and long-term extraction rate of 22% is imputed. Average K_2O content is 23%. With 5% clay the sp. gr. of the ore is ×2.128. Hence, one attains the figure 6137 million T K_2O of conventionally mineable reserves, i.e., 1.2% of the sylvinitic reserves *in situ*.

The remaining area, deeper than 4000 feet (1219 m), where solution-mining can be applied, covers 22,542 sq km where all 3 zones overlap (A), with additional 7674 sq km where only 2 zones overlap (B). Losses for brine areas (b) can be neglected in this case. Indentations according to Gorell and Alderman (c) are calculated at 15% and those with grades lower than 16% (d) are calculated at 20%. From this result the reduced area for (A) is 11,036 sq km and for (B) 3757 sq km.

Checking some models considered earlier in the alpine solution salt mines, certainly under quite different lithological and structural premises, but keeping the geoconditions in Saskatchewan in mind, an extraction rate of 22% (accidentally the same as dry mining) seems reasonable. This rate and the overall method are supported by the fact that by use of NaCl brines of different grades and slightly changing pressures, crystals of the halitic interbeds crumble and serve as an in-place backfill. Also, within the sylvinitic beds a collapse of a part of the halite-portion takes place and some halite also is reprecipitated.

*Occurrences which are not published but observed in different mines in Saskatchewan.

Losses by collapse of KCl crystals and mantling by claymud must be considered and are estimated at perhaps 20%.

TABLE II

	Million m^2	22 % E.R.	Av. Sy thickn.	Bill Spec. Grav.	Loss %	K_2O %	metr. K_2O
(A)	11036	2428	31	2.15	20	18	23,303
(B)	3757	826	18				4,603
			Mineable by solution mining: 27.906 ≅ 28				

Together with the conventional mining the result is 34 billion T K_2O as mineable reserves. That is 6.7% of the inplace sylvinitic stock.

THE PERMIAN (KUNGUR) PRE-URAL-TROUGH UPPER KAMA DEPOSIT: SOLIKAMSK-BERESNIKI

The planimetry of Figure 9 results in 3000 sq km of potash distribution. Four hundred seventy-one drillings (1973) provide a good basis for determining facies and thickness changes, disturbances and reserves. The mineralisation is uniformly chloridic with a clay content of 3% to 5% (Ivanov, 1969).

The sedimentary column (Figure 10a) by Rajevski (1973) shows that 6 of 13 potash zones are to a different degree intermissive, f.i., at KrIII, with about 35% proportional losses, at G about 15%, the other in between. Figure 10b (after Ivanov, 1975) with the transversals in the column is not contrary to a) but gives no clue on the share of barren parts.

The lower figures in Figure 10b up to E give the thicknesses if the zone is sylvinitic, the higher ones if carnallitic.

A. A Ivanov (1975) published 10 areal maps of the 13 zones or cycles separating 3 genetically different sylvinites (red, banded and coloured), carnallitic parts, sylviniticcarnallitic-mixed areas, subareas of higher grades, but almost no NaCl islands. Numerous tables like the 2 selected examples below give areal figures and specified losses for all 13 zones from KrIII up to K (Table III). Within the area of KrII, the sum of facial losses is 0.9%, after Rajevski at KrII (Figure 10) more than 25%. There are similar divergencies on the other distribution areas. Assuming that

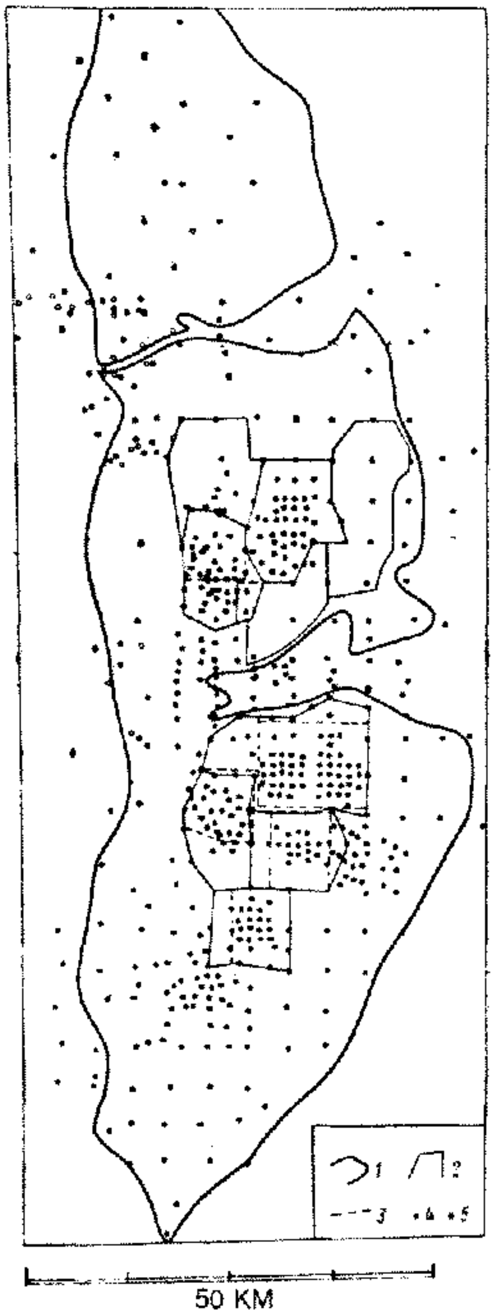


Figure 9. Area and drilling grid of Solikamsk-Beresniki, after W. I. Rajevski and M. P. Fiwega, 1973.

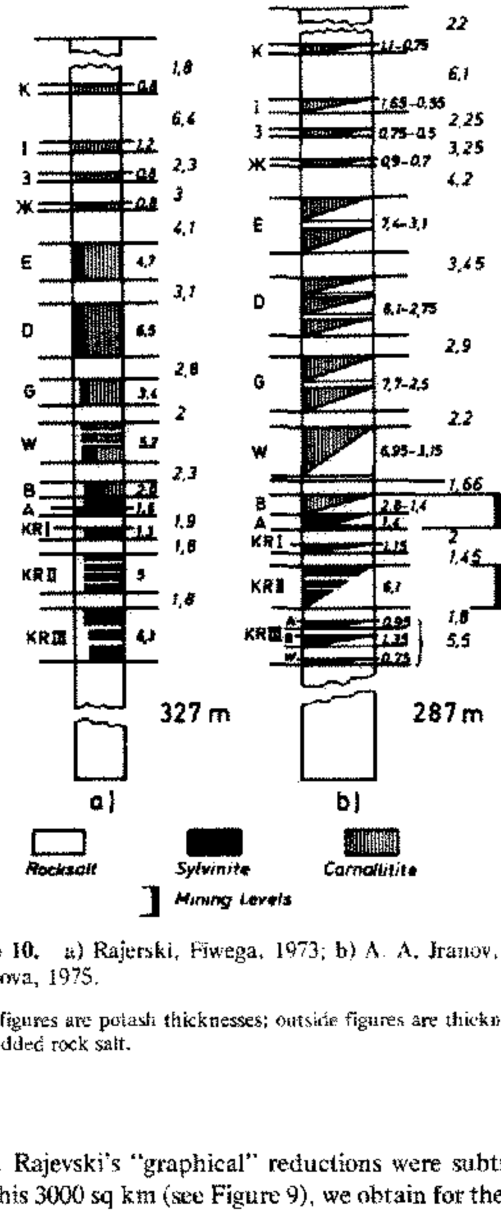


Figure 10. a) Rajerski, Fiwega, 1973; b) A. A. Jranov, M. L. Yoronova, 1975.

Inside figures are potash thicknesses; outside figures are thicknesses of interbedded rock salt.

W. I. Rajevski's "graphical" reductions were subtracted from his 3000 sq km (see Figure 9), we obtain for the habitat of KrII 2250 sq km, whereas A. A. Ivanov (Table III) obtained 2701.4 sq. km. Considering the particular accuracy, of Russian authors, those discrepancies may be due, perhaps, to different interpretative comprehension.

TABLE III

Sq km (%) of the Respective Habitat

Zone	Area	Intraformat. Rocksalt	Suberoded portions	Sylvinite	
Kr.II	2725.7	22.2 (0.8)	2.1 (0.1)	2701.4 (99.1)	Ivanov 1975, p. 131

		Carnallitite	Coloured Sylv.	Komplex Pot. salts	Intraformat. Rocksalt	Suberoded Portions (p. 138)
K	1710.4	1423.6 (83)	207.3 (12)	23.1 (1.5)	31.6 (2)	24.8 (1.5)

A. A. Ivanov releases only KCl contents of interbedded rocksalt. W. I. Rajewskij (1973 p. 121–126) submits proportional averages for the layers Kr.III–I and the double seam AB on thicknesses and KCl contents.

Using the areal figures and sylvinite thicknesses given by Ivanov and the contents of Rajewskij, the result shows: 23,025 million T KCl or 14,545 million T K_2O *in situ*. Taking into account the graphical areal reductions according to Rajevski (Figure 10a), the adjusted results are: 17,132 million T KCl or 10,822 million T K_2O in situ.

Considering only hypothetically in this case the carnallitites from Zone B upward, using the greater thicknesses, according to Figure 10b, and assuming a 50% carnallite content (= 8.475% K_2O), one obtains additional 10,500 million T K_2O, in place.

A. A. Ivanov (1969) claimed for this greatest Russian deposit "150 up to 160 billion T of potash salts" or "25–30 billion T K_2O," (i.e., an average K_2O grade of 15.6–(18.75)%). Together with the carnallitite, the total here presented result is 21 up to 25 billion T K_2O, the latter figure in accordance with A. A. Ivanov's lower figure. That shows 4.85 million T K_2O in sylvinite (and carnallitite included, 8.33 million) per sq km.

Before coming to the mineable reserves, some basic information is helpful. Above the lower rocksalt, which is 250–400 m thick, the potash sequence follows with a thickness of 30–125 m (see also Figure 10). Above this, there is a sometimes entirely sub-eroded salt roof, averaging about 25 m. An alternating sequence of originally existing rocksalt, now mostly sub-eroded, and claystone, which changes substantially in thickness (max 80 m), passes up to the upper Kungur member, a lime-sand and clay-sand stratum, which is about 25 m thick.

Smaller quantities of brines occur frequently and there are relevant quantities of methane and hydrogen within the mined potash beds. The mining takes or took place at depths of 75–450 m (Ivanov, 1969) or 70–350 m (W. Gimm, 1968). There are even disturbances in the uppermost portions of the saline formations from former long-term solution mining of rocksalt.

Taking the areas of A. A. Ivanov and using the reductions according to the earlier enumerated loss-categories:

(a) Settlement protection (it is reported that backfill is planned or performed below the town of Solikamsk), water reservations, roads a.s.o. with 10%
(b) Intraformational disturbances, i.e., more or less barren shares, diminishing thicknesses, and pillars for brine- or gas-endangered portions. 20%
(c) Extraction rate 37%. Average K_2O content of the hoisted ore, 17%. (Both figures came from competent official visitors).

At Kr.II: 2701 (sq km) ×0.75 (b) × 0.9 (a) × 0.37 (E.R. × 5 (m) × 2.134 (sp. G.) × 0.17 (K_2O) = 1305 million T K_2O.

At AB: 2479 × 0.75 × 0.9 × 0.37 × 3.6 (m) × 2.125 × 0.17 = 805 million T K_2O.

The *mineable reserves* can be calculated as 2.110 billion T K_2O, and are 14.5% of the sylvinitic reserves in place.

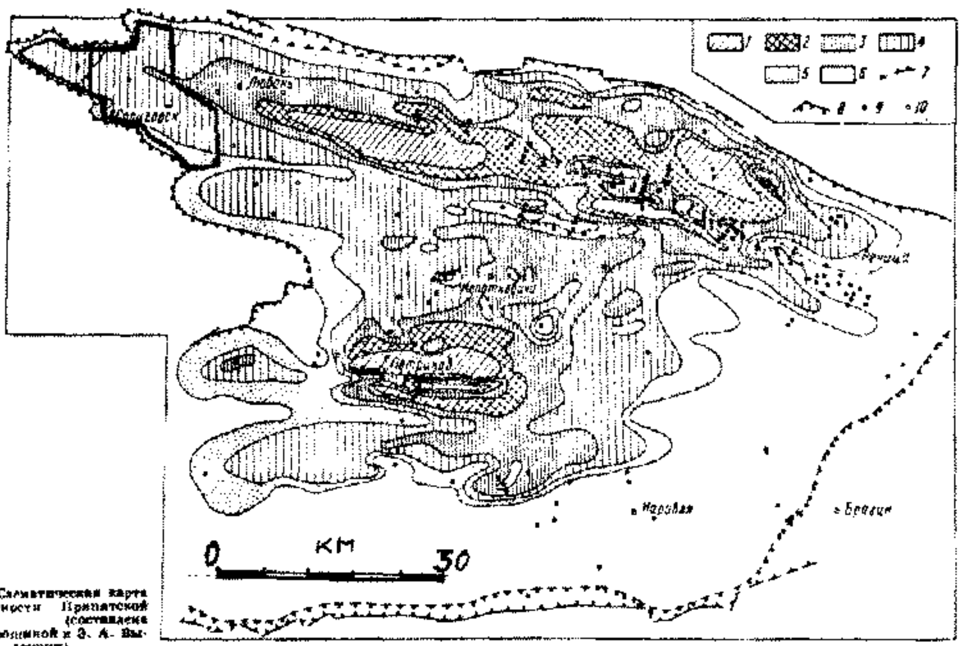


Рис. 9. Схематическая карта калиеносности Припятской впадины (составили Д. М. Ерошиной и З. А. Высоцкий).

Figure 11. After D. M. Eroshin-I. A. Visotsky. 1: up to 13 cycles; 2: 9–12 cycles; 3: 5–8 cycles; 4: 1–4 cycles; 5: Potash-bearing rock without distinguished seams

THE UPPER DEVONIAN PRIPIAT DEPRESSION

The map (Figure 11) shows the extension of the salt basin—named after the cities of *Soligorsk* and *Starobin*—having approximately 10,000 sq km.* It discharges to the southeast after passing a sill into the equally salt-containing, 630-km-long Great-Donbas-Graben. The depth of the salt formation goes to 2870 m and it contains about 30 potash cycles (A. A. Ivanov, 1969). Only sylvinite and carnallitite occur. The potash beds I–IV can be traced continuously from 485 m to 1488 m depth.

About 340 boreholes were drilled up to 1973. The depth of the deposit increases from NW to SE (Figure 12).

The actual mining area is situated in the northwest corner of the basin and is divided into four large mining fields covering 640 sq km. The "geological and prognostic" reserves amount to more than 36 billion metric T of potash salts, according to A. A. Ivanov (1969). He stated a median KCl content to be 11–12%. Taking 11% (= 6.948% K_2O), the total in situ reserves of the whole Pripiat Basin would be 2.333 billion T K_2O.

The potash seams I–IV (Figure 12) are shown in; the recoverable seams II and III are marked by circles. The deposit is very slightly inclined, practically flat. Rajevskij and Fiwega (1973, Table 6, p. 49) present the "A + B + C" reserves in 1000 T, as sylvinite and K_2O within a depth limit of about 1000 m. The list below shows only the K_2O-quantities:

Potash Zone I	123,755	
" " *II*	91,732	203.036
" " *III*	111,304	
" " IV	226,548	
	583,339 in place.	

For the two mined layers II and III Rajevskij and Fiwega (1973, p. 45, 46) present data for the four mining fields separately. A simplified summary is given in Table IV (below).

From this list, obviously the result of extensive probing, proportional average thicknesses and content in situ cannot be immediately derived. But the range of variability may characterize the deposit.

The strata-columns of the layers II and III demonstrate the unavoidable high dilution from halite interbedding. Considerable stress problems from the clay-carnallite alternation above the lower mining section, as well as the

*The Russian authors frequently do not include scales with their distribution maps. Therefore, the distance Soligorsk-Liuban, respectively Petrikov, has been taken from an atlas and used for planimetry. That is not very accurate.

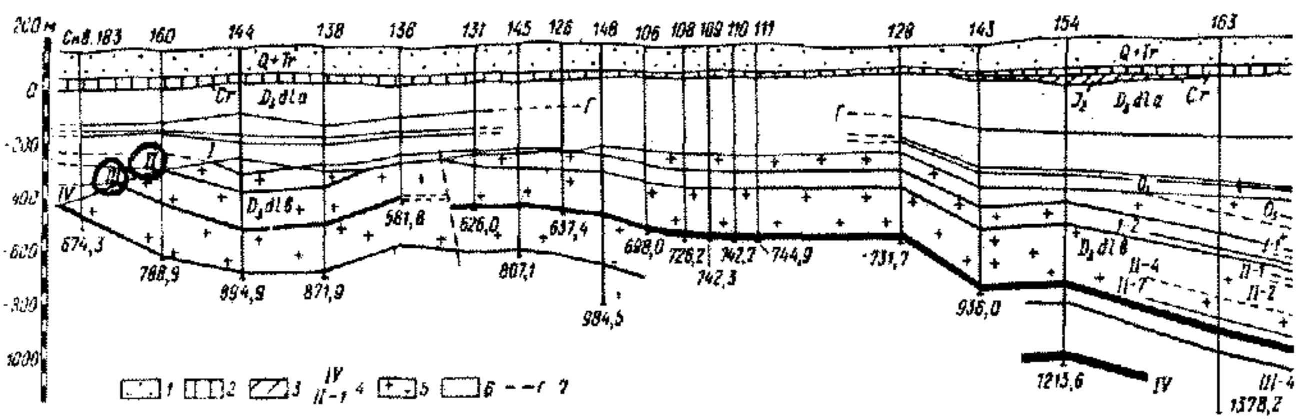


Figure 12. After D. M. Eroshin and O. K. Liachov.

1: Quaternary-tertiary, 2: Cretateous, 3: Jurassic, 4: Roman figures: the potash seams, 5: Rock salt, 6: Overlying clay and marls, 7: top of the occurrence of gypsum

TABLE IV

	Field 1			Field 2			Field 3			Field 4		
	Thickn. m	KCl %	Ins. %	m	KCl %	Ins. %	m	KCl %	Ins. %	m	KCl %	Ins. %
II	2.6–2.74	30.19–32.2	2.7–6.9	2.19–3.34	23.3–35.3	4.1–11	1.7–3	14.4–35.5	3.8–12	1.4–2.5	15.5–31.7	0.9–9.9
III upper bank	1–3	12–20	1.5–6	1.5–2.7	11.75–20	3–10.9	1.5–3.8	14.5–22	4.5–8.5	1.5–2.8	9.9–18	3.4–8.27
III lower bank	4.8–5.8	15.6–24.5	3–7.8	3.6–6.1	14.2–26	2.5–15	2.3–4.7	22.2–26.2	2.4–5.3	2.4–5.3	15.7–35	3–12.8

extraordinarily high clay content in the ore, should also be noted. Even without further information, the probability of coincidences between expanded halite intercalations and thinned sylvinite justifies reductions for local impoverishment, as well as for primary failures of sylvite precipitation and possible secondary removal. The assumption that the sum of all depositional losses can be postulated as being at least 20% appears reasonable.

Rajevskij and Fiwega (1973, p. 59) quote the reserves of the not-mined potash beds I and IV to be 2 billion T rough ore, within a depth of 1000 m and 560 sq km. Given 20% depositional losses and an average K_2O grade of 15.1% (counted back from Table 6, p. 49, Rajevskij and Fiwega, 1973), other in-place reserves amount to 241 million T K_2O.

When the earlier mentioned 203 million T of the mined seams are added, the total "in situ reserves" come to 444 million T K_2O within the named depth and areal limits. Coming back to the 203.036 million T K_2O (A, B, C) in the mined layers II and III, it is assumed that the geological losses have not yet been subtracted. Using an extraction rate of 40%, the result is 65 million T K_2O in mineable reserves (according to Permiakov, 1973).

If we take as a basis the 1.2386 billion T Sylvinite of II and III (Rajevskij-Fiwega, 1973, pg 49) reduced by 20% for natural losses, using the same extraction rate and assuming 11% K_2O in the hoisted rough ore we obtain 43.6 billion T K_2O in mineable stock (according to W. Gimm, 1968).

The last named parameters were commonly accepted until 4 or 5 years ago. Since then the mining provisions have changed entirely because of the installation of a long-wall and roof-fall system. This is obviously possible—without drowning—because of the self-sealing properties of the salt clays and the thick overlying clayey marl.

Layer II is fully cut and layer III is mined along two separated overlapping cuts, leaving behind an interbedded salt bank of about 1 m thickness. The lower sylvinite bank can be completely removed down to a thickness of 0.8 m.*

Sagging of the surface is accepted and amounts to ap-

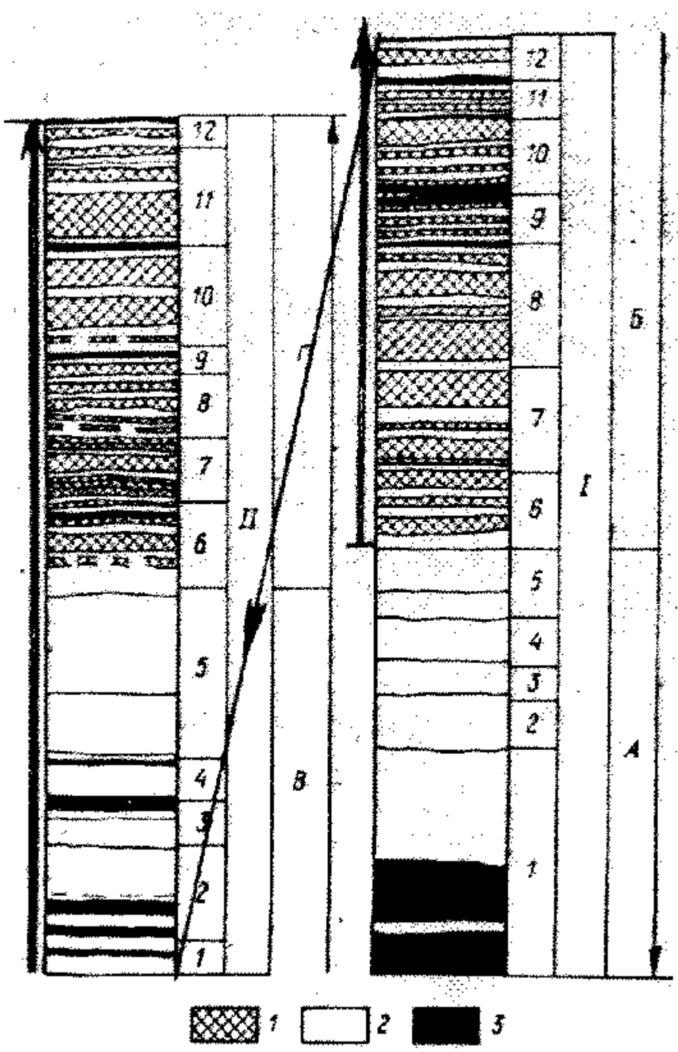


Figure 13. Layer II (after W. I. Rajevskij and M. P. Fiwega).

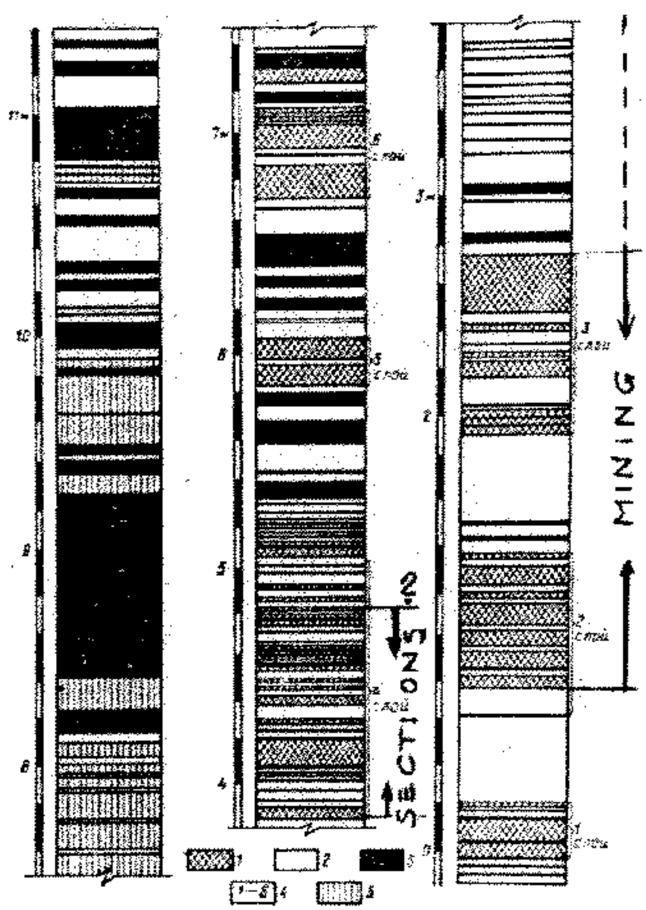


Figure 14. Layer III (after W. I. Rajevskij and M. P. Fiwega).

1: Sylvinite, 2: Rock salt, 3: Clay 5: Clayey carnallite

*The West German equipment used with continuously variable cut height works with a swivel-mounted drum system.

proximately 60% of the excavated heights in the first stage. If it proves to be a safe longterm technique, the permanent improvement of the extraction rate from 40 to 80% or more, and an increase of the K_2O content of the hoisted ore from 11 to 16% can be expected. (The "Technologia kalinich udobrenji—1978" quoted KCl contents between 26.9 and 24.8% = 17.0 – 15.6% K_2O.)

In summary: the in-place reserves within one thousand m depth limit are 444 million T K_2O, all 4 potash beds included. The mineable reserves of II and III, based on an extraction rate of 80% and a K_2O grade of 16% of the hoisted ore, increase from about 43–65 million T to 126.835–129.943 million T K_2O, minus the production of about 30 million T K_2O since the release of Rajevskijs-Fiwega's reserve figures. This means approximately 100 million T K_2O, now about 22.5% of the in-place reserves.

THE MIOCENE PREKARPATHIAN DEPRESSION, STEBNIK-KALOUSH

The long (approximately 170 km) and variably wide (15 km) trough contains a series of clayey salt or salty clay and shales with some marker horizons above the basal anhydrite and gypsum-bearing clays, and closes near the top again with gypsum-clay. Numerous listric faults follow the structural E-W strike and dip to the South toward the Karpaths. There are also structure crossing faults (see Figure 16). The salt bodies and potash beds within this faulting network are intermittent and distorted as shown

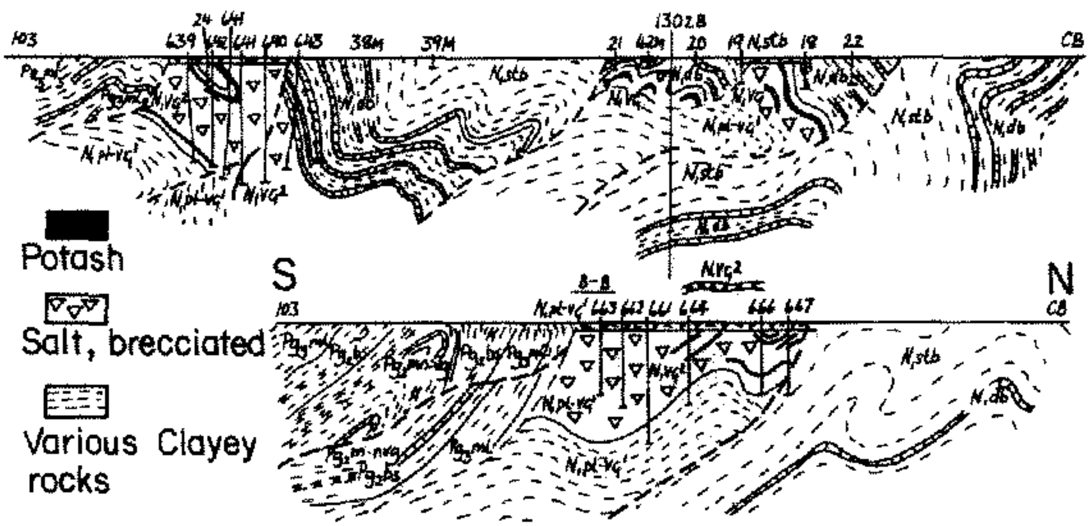


Figure 15. Miocene pre-Carpathian Depression After Rajevski.

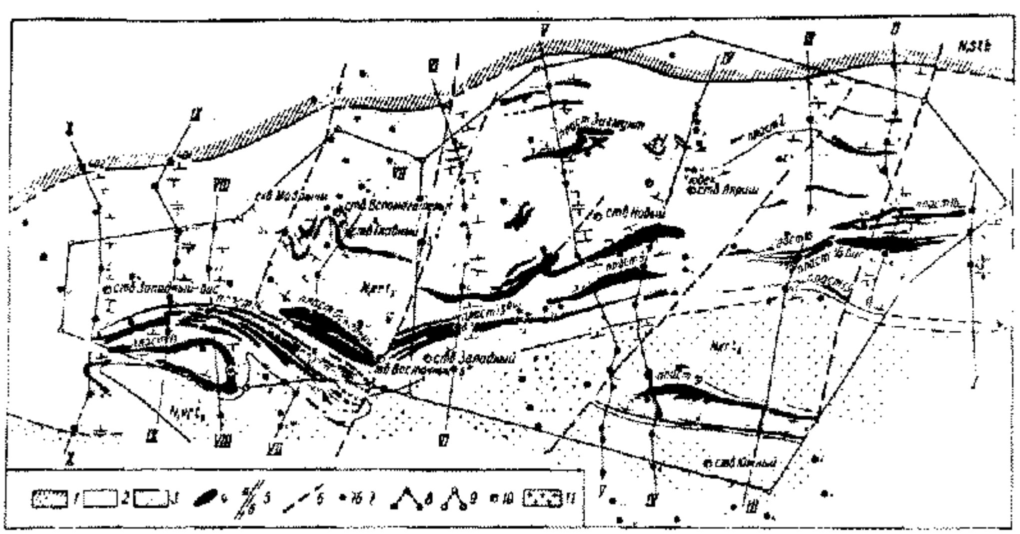


Figure 16. The area around Stebnik at the 240-m level, after Yu. E. Kudriavtsev and W. A. Samojlov. 1: Saline formation, 4: potash seams, 6: faults

also on maps and profiles by W. N. Stupnitskij (R.-F. 1973) or C. M. Korenevskij and K. B. Dontshenko (1963).

It appears to the writer that this is an illustrative example of a compressed foredeep with the characteristics of molasse-tectonics (see Figure 15). It reminds one of similar structural appearances in the Sicilian Miocene salt channels, though here the tectogenesis differs.

The basin contains 15 scattered salt bodies. They carry 2 to 5 strongly folded, lenticular, about one- to five-meter-thick potash horizons of polymineralic composition. The upper potash seams contain variable proportions of Kainite and Langbeinite with some Sylvite; the lower seams contain mainly poor polyhalitic salts. Rajevskij and Fiwega (1973, p. 202) present tables of the main mining fields with average contents of kainite, polyhalite, kieserite, epsomite, shoenite, leonite, astrakanite and glaserite, quoting the K_2O grades, which range between 9.8 and 11% *in situ*. A more topical but similar list was released by Kashgarow and Sokolov, (Techn. Kalin. udobrenij 1978).

The clay content varies between 10% and 18%. The hoisted salt contains about 10% K_2O or less. The mining takes place at depths between 80 and about 800 m.

Quite obviously all efforts were made to find and explore new potash occurrences in this trough, as may be recognizable by the high numbers of wells currently being drilled, like no. 761 to be seen on a profile by W. N. Stupnitskij.

Rajevskij and Fiwega (1973, p. 204) released the following in-place reserves ($C_1 + C_2$) of the currently operating mining fields:

Down to 600 m depth	476.96 million T ore with 52.67 million T K_2O,
to 1000 m depth	682.45 million T ore with 76.24 million T K_2O,
together	129 million T K_2O

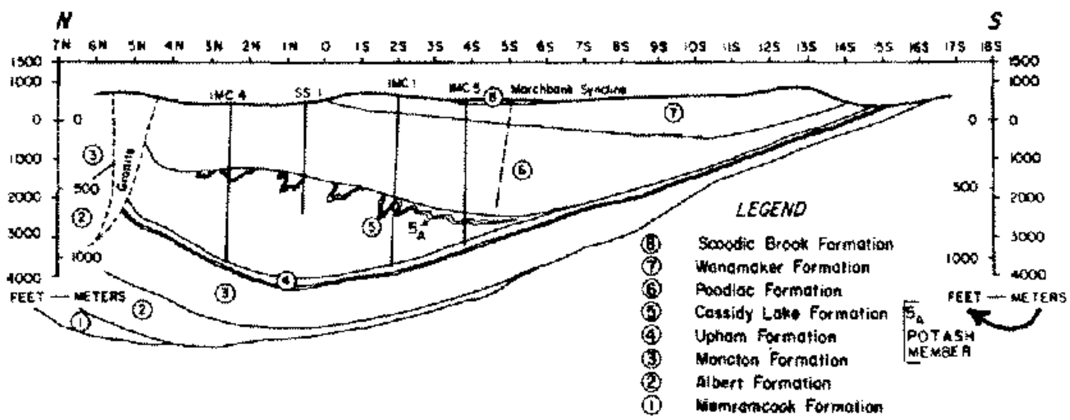


Figure 17. Cassidy Lake deposit, after Anderle, Crossby and Waugh.

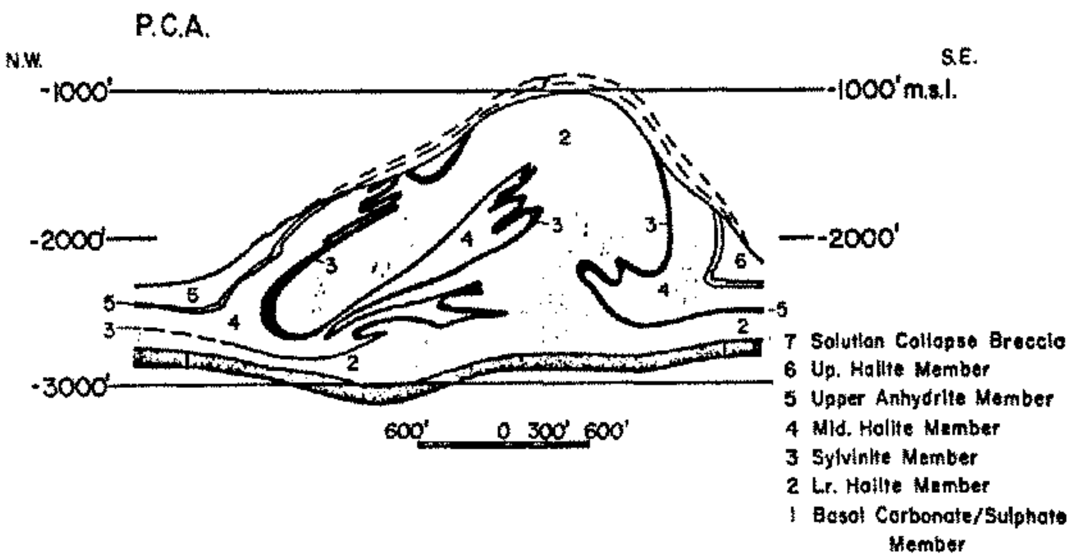


Figure 18. Anagance Anticline, after F. W. Kingston and D. E. Dickie (1977).

The extraction rate is 39%, according to personal information. This seems somewhat high, considering the changing, often small thickness, disturbances by faults, and changing, mostly unfavourable dips. Based upon these figures, 25–50 million T K_2O mineable reserves remain (25 million T K_2O is estimated by the writer because of the high degree of uncertainty of C_2 reserves.)

It is obvious that the pre-carpathian deposits are very complicated and from the mining point of view problematic. But it is the sole natural resource of potash-magnesia-sulphates in the USSR.

THE MISSISSIPPIAN SALINE-BASINS IN NEW BRUNSWICK, CANADA

Two of three potash-bearing subbasins are located in the bigger Moncton-Basin, with the Anagance "anticline" and its southwestern panhandle, the Millstream structure. The third is the isolated Marchbank depression with the Cassidy Lake deposit. The saline formations belong to the Windsor group, which is equivalent to the European lower Carboniferous about the Dinantian.

The potash salts are pure chloridic, sylvite and carnallite, and the ore is nearly free of insolubles. The shape of the basins and the type of halo-plastic deformations suggest a passive reaction to lateral stress across the axis of the basins.

According to W. C. Gussow (1953) and also to J. B. Hamilton (1961), the regional tectonic stress came from the northwest and abuts the Caledonian crystalline range on the north bank of the Bay of Fundy. The picture Figure 17 shows at first sight a tilted and cross-squeezed basin. If the crest or bottom lines of the folds strike aproximately parallel to the longitudinal axis of the basin, then this could be considered a further indication of a passive "squeeze-box" folding. In such a case it is allowable to use a stretching factor to obtain the area of potash beds in reserve calculations. A sufficient knowledge of the folding amplitudes from an adequate drilling pattern is presumed.

This is, of course, not to transfer to an anticline like Figure 18, though substructures like that inverse of f.i. the middle halite-member (4), certainly continues in more or less changing shape over a given length along the general strike and can be sized. Even this anticline, with its two semi-symmetrical overlapping "lower halite" wings (2) and the steeper structural elements southeast, shows also a salt body squeezed through north-to-west stress.

Such points of view can be used as interpretative support, estimating the reserves in that region.

The reserves of the Sussex area (N.B.) are somewhat reduced by occasional parallel running carnallitite. Nevertheless, the sylvinitic stock of the three deposits may be about 700 to 900 million T. The exceptionally constant grade allows a rather conservative assumption of 26% K_2O. This yields 182–234 million T K_2O in situ. Considering the different structural conditions of the three ranges, a medium extraction rate of 40% could be assumed (no back-filling anticipated). Taking 182 million T in place, about 70 million T K_2O mineable reserves can be assumed as an absolute minimum.

THE PERMIAN DEPRESSION IN NEW MEXICO AND THE PENNSYLVANIAN PARADOX BASIN, USA

There has been a great deal published in America concerning New Mexico's potash range from H. J. Smith (1938) and G. A. Kroenlein (1939) up to J. C. Dunlap (1951) and then C. L. Jones (1954) with his studies about the mineral distribution, C. L. Jones and B. M. Madsen (1958) with their mineral facies map of the 5th ore zone, K. O. Linn (1965) with information about the occurrence and distribution of barren zones, and many others. However, although a comprehensive overview of this polymineralic and not exactly stratabound deposit can be obtained, the reserve situation was not part of their consideration.

Works like those of R. J. Hite or R. B. Mattox, dealing with the Paradox Basin, were also pursuing scientific aims not concerned primarily with reserves. Therefore, data should be taken from the U.S. Bureau of Mines whose 1980 Edition of "Potash Mineral Facts and Problems" states that the average K_2O content in the Carlsbad district was 13.5% in 1979, and that apparently for the sake of improvements of the "second mining system," an extraction rate close to 90% was achieved.

In an earlier edition (1965) the following reserves, supplied by R. J. Hite from the Geological Survey, were quoted:

Paradox including SE Utah and extending to SW Colorado	
Known reserves	230 million metr. T K_2O
Inferred reserves	146 million metr. T K_2O
Permian basin Carlsbad, N.M.	
Known reserves	77 million metr. T K_2O
Inferred reserves	360 million metr. T K_2O
	(sylvite and langbeinite undivided).

Subtracting the production since 1966 of about 40 million T from known reserves in the Carlsbad area (at 90% extraction rate), remain 33 million T K_2O of mineables. The *in-situ* potential, Paradox basin included, amounts to 800 million T K_2O. But the mineable reserves of the Paradox region by solution, without the advantage of a flooded mine, like Moab, are very hard to estimate, considering the structure and lithology of the deposit.

SERGIPE, BRAZIL AND HOLLE, CONGO-BRAZZAVILLE

Sergipe, Brazil. Jose C. Fonseca (1973) gave a thorough presentation of all findings of the two main subbasins of

Sergipe: Sta Rosa de Lima and Siririsinho-Vassouras together with Carmopolis-Taquari (Figure 19).

There are 10 cycles, similar to Congo-Brazzaville, in which carnallite and tachhydrite predominate up to the sixth cycle. Both saline sequences exhibit a typical misproportion to the extremely receding inter-bedded rocksalt. The KCl reserves in Vassouras-Taquari are given to be 179 million T, a realistic figure, as shown by the basic data of J. C. Fonseca. On the other hand, the mineability seems to be an open question, considering the almost regularly subjacent thick tachhydrite, occasionally separated by a couple of meters of carnallitite.

Certainly we have no practical experience of the stress behaviour of tachhydrite, but we see its extreme fossil deformation and the recent stress reactions of its near relative, the carnallite. Taking into account a protecting plate of only 5 m in the lower part of the sylvinite seam, only little or sometimes none is left to mine. But the Santa Rosa de Lima Basin shows a competent underlying rocksalt bed having thicknesses between 15 and 74 m. The salt roof between 27 and 75 m up to the top appears sufficient to maintain stability (except one case with about 6 m). The sylvinite bed in Santa Rosa is between approximately 3 and 7.5 m thick and shows a surprising lateral and vertical grade constancy. The depth of the sylvinite bed is proven between 530 and 850 m.

The writer mentioned in an in-house study (1971) that the basin has been strained tectonically. It dips 8° to the north; shows a plain convexity in the center, and a rather steep dipping (approximately 30°) in the west wing down to depths of more than 1200 m. That requires compensating movements of the salt body in direction of the stress-release, i.e., to the less thick clastic overburden. Accordingly, there are bed repetitions, although only in one or two drill holes. In one case it is an overturned fold with a vertical amplitude of 40 m. That can scarcely be a unique phenomenon. Even the changing level of the potash bed to the salt top indicates a mobilized, wavy shape. Therefore, the sylvite reserves of Santa Rosa of 76 million T (according to Fonseca (1973) p. 193) may be multiplied by a stretching factor of 1.3 and increase to approximately *100 million T or 63.17 million T* K_2O *in situ*. Subtracting 60% for depositional and mining losses, approximately *25 million T mineable reserves* remain.

Congo-Brazzaville. It may be noted that in spite of the similarity or better geological identity of the two deposits, the sylvinite of Sergipe (in any case in Santa Rosa) represents a precipitated sediment. But in Holle, Congo-Brazzaville, it is the result of a secondary hydrometamorphosis of carnallitite (Figure 20).

The "mirror" S_1 is plane and sharp like a knife cut, a particular kind of a hydrometamorphical "disconformity,"

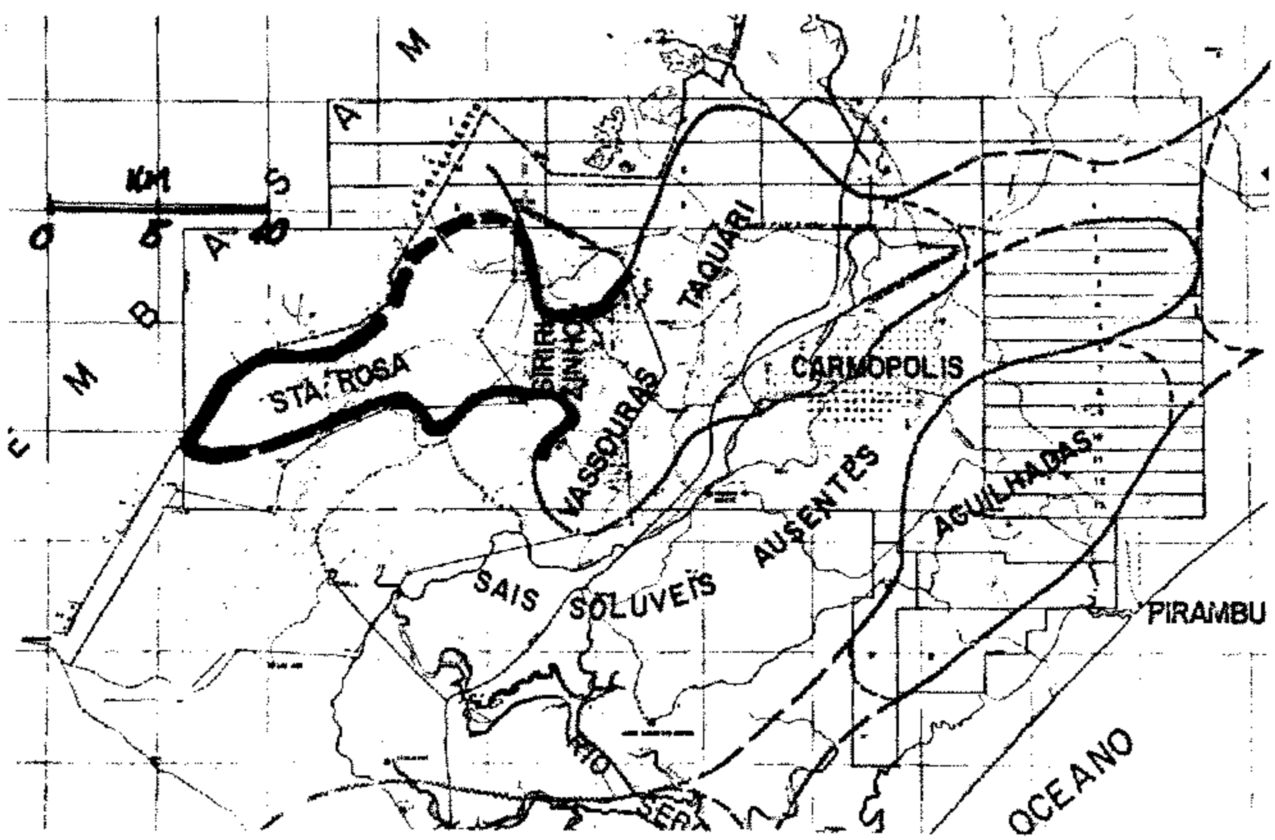
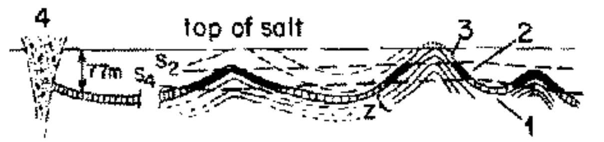


Figure 19. The Salt Basin of Sergipe, after J. C. Fonseca.



1. carnallitite
2. sylvinite
3. halitic (barren) potash-bed
4. unconsolidated break-in of clastics

S_2. transformation plane ("mirror") from highgrade sylvinite to halite.
S_1 mirror from carnallitite to sylvinite.

Figure 20. W-E cross-section of the mining area of Holle (Congo Bru.)

The mine drowned in 1977 in less than 2 days after running into the break-in (4) with a drift.

The problem here, besides the latent high danger of water influx, is to find some more extended spots with secondary sylvite, a similar situation to the Khorat Plateau in Thailand. The carnallitite is valueless for the present and the forseeable future. Reserves cannot be named.

EUROPEAN TERTIARY-DEPOSITS

Catalonean Upper Eocene, Spain. The salt-bearing Prepyrenean rim-syncline is about 360 km long and covers an area of about 15,000 sq km. Its two ends contain relatively small potash subbasins, Navarra with approximately 400 sq km in the WNW and the Catalonean with approx. 630 sq km in the ESE. The latter figures are uncertain because of a rather widely spaced drilling pattern. Therefore, even statements on regional distribution of the four potash zones—A, B, C and D—are not possible. But the areas inside the circuits of the mining sites of the salt plug of Cardona and the overturned anticline of Suria, together with the flat-lying deposit of Balsareny and Sallent, have been investigated variously and are well known.

Some basic data according to J. J. Pueyo-Mur and A. San Miguel Arribas (1974): In Suria, the lower beds A (3 m) and B (2 m) and the upper C and D carnallitic beds are sufficiently separated by rocksalt banks. In Balsareny the thickness of the sequence from A to the bottom of C is diminished to a quarter, and in Sallent by another third. On the latter locations the sylvinite B is immediately overlain by the carnallitite of C and D. The flat deposits mentioned are at depths of 450 and 560 m. Both sylvinitic layers are being mined.

According to C. Castells (1977), the average K_2O grade of the sylvinite is 11% in Cardona, 17% in Suria and 12.5% in Sallent. The barren share in Balsareny, according to R. Gonzales-Santiago (1978), is 25%.

The *in situ* reserves, according to previous estimations, ranged from 500 million T to 9.5 billion T K_2O, with only the sylvinite considered. A later study in the context of the "Second Development Plan" quotes *100 million T K_2O in situ* in the Catalonean part and 80 million T in Navarra, according to C. Castells (1977).

The mining Companies list the "secure" (or "proven") reserves at 4.24, the probables at 49 and the possibles at 71 million T K_2O in Catalonia, and unrisked at 23 million T in Navarra—all as sylvinite. Restricted to Catalonia because of the high proportion of carnallite in Navarra and other problems, the in-place quantities, proven and probable, come to *53 million T K_2O*, assuming natural losses in the flat part at 25% have been considered. Supposing a general extraction rate of 40%, the mineable reserves come to *21 million T K_2O* present value.

The Oligocene Basin in the Upper-Rhine-Graben, France. The age of the saline formation is lower Oligocene, i.e., the Sannoisian. In the center of the basin at about Mulhouse it is built up at a thickness of 1700 m on the siderolitic Eocene basement and consists of an alternating sequence of marls and rocksalt.

The dominating clastics (see Courtot and Assoc., (1972) are occasionally interbedded with thicker (60–120 m) rocksalt units (Staffelfelden, according to L. Lagneau-Héranger, 1961).

In the upper-Sannoisian, in the so-called upper bituminous zone, the two sylvinite beds occur separated by 20 m of rocksalt with one interbedded anhydritic dolomitic marl bank (about 3 m).

The basin is tectonically characterized by uplifts and descended parts along north-south striking faults; in the north some diapirs occur.

The upper bed, according to L. Lagneau-Héranger (1961), is 1.5–2 m thick, after R. Sellal (1972), 1.5 m and contains 20–25% K_2O. The average, according to W. Wagner (1953), is 22%. The lower seam is 2.5–5 m thick, contains locally carnallitite in the uppermost section and has 15–20% K_2O—average 17% (according to W. Wagner, 1953). At the borders of the potash beds the contents diminish to 11% and less within a broad rim.

An average depth is mentioned with 635 m below surface. Mining takes or took place between 400 and 1100 m. The seams are proven in depths between 300 and 1200 m. The dips vary from flat to half steep, i.e., the mining occurs up to a dip angle of 25° (according to M. Breniaux, 1981). The salt roof varies between about 200 and 550 m in thickness. The area of the upper bed is about 115 sq km, that of the lower bed 300 sq km.

With 317 drillings, the basin, according to R. Sellal (1972), has been very thoroughly investigated in comparison to other European potash regions. W. Wagner (1953) estimated the in-place reserves of sylvinite in the upper seam to be 250 million T and in the lower seam to be 1300 million T. Lagneau-Héranger (1961) estimated a bulk of 2000 million T with 17% K_2O and from this 340 million T K_2O in situ. Taking the 1550 million T of W. Wagner and assuming an average of 14% K_2O, the broad, relatively poor rims included, one obtains 217 million T K_2O in situ, without consideration of depositional losses. Assuming natural losses for disturbances of any kind and poor rim areas at 35–40% and a longterm extraction rate of 65%, about 90 million T remain. Subtracting the mined-out quantity since 1904 of approximately 70 million T, the mineable reserves come to 15–20 million T K_2O.

One might recall here, according to M. Breniaux (1981), that a long wall and roof fall system introduced several years ago works because of the favourable overlying rock, similar to the Pripiat-deposit. The relatively quick sagging of the surface is even taken into account.

The Miocene (Messinian) Deposits of Sicily. The 12 subbasins are irregularly strung along two more or less parallel NE-SW-striking, 115-km-long channels, which are between 2 and 7 km wide and funnel up on the southwest coast to 11 and 25 km between Sciacca and Agrigento, according to L. Ramberti (1980). They are separated by a mainly Tortonian, 2.5-km-up-to-16-km-wide streak.

The halo-petrographical and stratigraphical conditions are fairly well characterized by an example of the sequence of San Cataldo-Palo (according to L. Ramberti). From top to bottom:

9.	stratum	approx.	40 m	halite with polyhalite and kieserite
8.	"	"	28 m	halite anhydritic, containing also polyhalite and kieserite
7.	"	"	14 m	like 9
6.	"	"	30 m	carnallite with sylvite and bischofite
5.	"	"	33 m	halite, kainitic
4.	"	"	*60 m*	*kainite* with alternating halite and kainite with kainitic halite
3.	"	"	10 m	like 5 (sometimes with some schoenite)
2.	"	"	25 m	halite with some intercal. kainite
1.	"	"	210 m	halite containing polyhalite, kieserite and anhydrite.

The fourth unit, the kainite, thickens in the subbasin of Pasquasia to 125 m.

P. Berry and R. Ribacchi (1976) published the following kainite and K_2O contents of a sequence of kainite beds from Pasquasia, from top to bottom:

TABLE V

Bed	Thickness (m)	Average K_2O-content (%)	Average-content of kainite (%)
1	5.5	17.4	90.3
2	29.0	14.5	75.3
3	4.5	16.5	85.6
4	10.0	11.2	58.1
5	3.0	14.8	76.8

The minimum K_2O content to be mineable is 12%, and the minimum thickness 3 m. To what extent the contents change in one and the same seam and the proportionate share of poor kainite ores has not been the object of published research up to now.

The subbasins are strained by gliding compression and the degree of deformation varies from a relatively moderate folding (like Figure 7) to strongly contorted structures.

The mining levels range in one field, e.g., between 380 and 800 m in depth.

Neither the general *in situ* potential of all 12 subbasins nor even the reserves with 12% K_2O or more in the 4 mining fields respective subbasins of Pasquasiva, Racalmuto, S. Cataldo and Milena were mentioned in geological publications. The writer knows only one statistic from San Cataldo Palo according to S. Adamo and L. Ramberti (1975). This mine hoisted, between 1958 and 1975, 15,386,664 mill T of kainitic rough ore. That is assuming 12% K_2O, 1.846 mill T K_2O.

The estimated resources, according to the world statistics 1980 of the U.S. Bureau of Mines at 30 Million T K_2O appear certainly probable; also the 10 million T reserves.* At a 50% extraction rate, 5 million T K_2O mineables remain for the time being.

GERMAN ZECHSTEIN

West Germany. The very extensive literature about the Zechstein saline formations cannot be dealt with within the actual frame, even given the fact that only a small fraction could be used for the object in question. Generalising, it can be said that the productive diapirs of the central Hannoverean region have to be treated geologically, and in view of mining according to their own regimes. The Werra-Fulda deposit exhibits some similar features to other slightly wavy occurrences, making no particular difficulties to size up its reserves. In respect to the diapirs, it may be worth mentioning that 6 out of 7 running mines, including the 1975 drowned mine of Ronnenberg and the deliberately flooded mine of Benthe-Hansa, have produced 40.45 million T K_2O since their start in 1899. That is an average of 6.75 million, with a maximum of 9.2 million T, and they are not yet exhausted. In order to demonstrate the contradictory judgments on the West German reserves, it is instructive to have a look at older and younger published figures:

Deutsches Reich	1922	2	billions T K (= 2.4 billion T K_2O), according to M. Meisner, Weltmontanstatistik 1924

*At the end of the exploratory phase conducted by an Italian-French-German combined team from 1956 to 1958, we have limited the relatively insignificant sylvinite resources to Pasquasia in our own reports but have estimated the kainite *in situ* resources in the region to amount up to approximately 60 million T K_2O, though that may be a bit too high.

Deutsches Reich	1931	20	billion T K (24 billion T K_2O), E. Fulda, "Neuberechnung," Weltmontanstatistik 1932
West-Germany	1968	1.8	billion T "recoverable K_2O," according to S. S. Adams, 1968
West-Germany	1970	9	billion short T K_2O "indicated reserves," according to R. W. Lewis, 1970
West-Germany	1972	9	billion short T K_2O "reserves," according to F. C. Kruger, 1973 resp. to the annual Report of Secretary of the Interior 1972
West-Germany	1975	3.6	billion short T "Total Resources," according to the Bureau of Mines, Bulletin 667, 1975
Federal Republic of Germany	1980	5.6	billion metric T K_2O "Total," according to the Bureau of Mines, Bulletin 671, 1980.

There are similar figures, mostly 9 billion T, also in Spanish, British (1979) and Russian statistics (see table on the last page). E. Fulda (20 billion) was certainly very familiar with the matter but rather hypothetic due to a small exploratory basis at this time. But where is the original source of those exaggerated figures like recoverables of 1.8 billion, and over 15 years "reserves" of 9 billion short T (= 8.164 billion metr. T K_2O), and on what facts are they founded?

The aspects of the problem can be explained briefly. The reserves of the Solling region and of the Werra-Fulda district can hardly be doubted. There is no space to enlarge them. About 100 diapirs in the north of Germany remain and contain (outside of the habitat of the Ronnen-

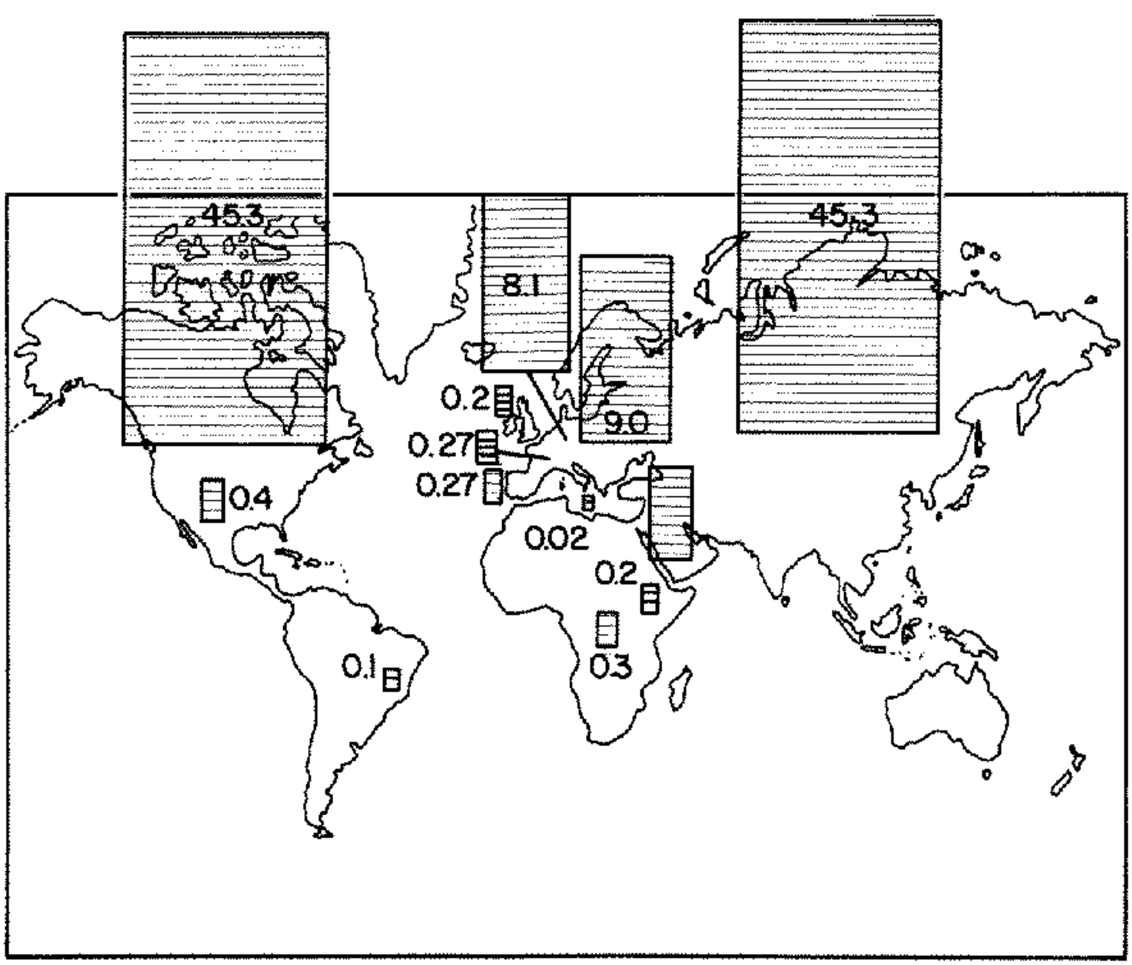


Figure 21. World potash-reserves in Billion T K_2O; compiled 1974. By chance a "potash-balance" between the western- and the eastern hemisphere. After Mühlberg, 1963; Iwanow, 1969; and Kruger, 1973.

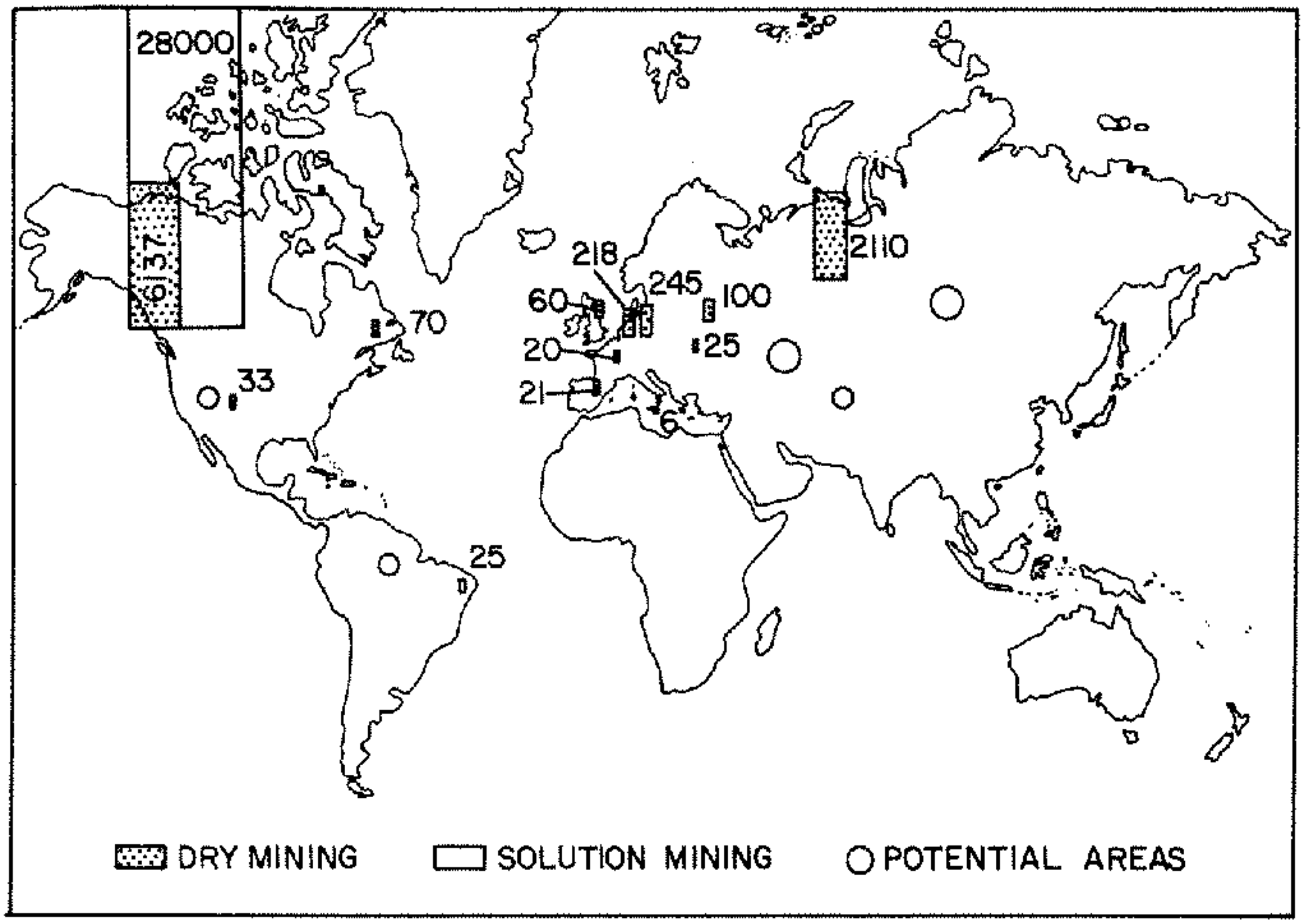


Figure 22. Recalculated respectively-estimated reserves (1983) of Mineable K_2O in Milliont.

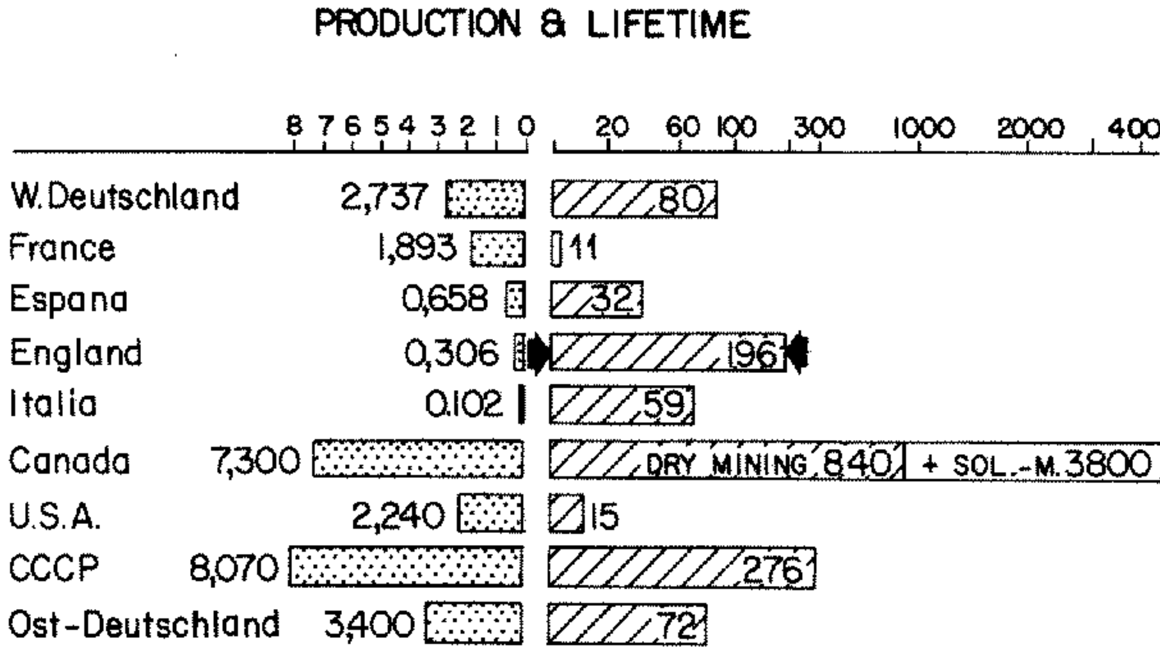


Figure 23. On the left side: Production in Million T K_2O in 1980. On the right side in logarithmic scale: Fictitious lifetime based on mineable reserves and constant production rates.

TABLE VI

World Reserves of Sylvinite and K-Sulfates

	Million T K_2O after Ivanov Voronova,[5] 1975 "Geol. Reserves"	Million T K_2O according to this paper	
		in situ	mineable
Saskatchewan-Basin, Canada	16,000-50,000	507,218	6,137 28,000[1]
Pre-Ural Through (Solikamst-Beresniki, USSR)	219,000 (rough ore)	10,822	2,110
Pripiat Depression, Soligorsk, USSR	50,000 T (rough ore)	444	100
Pre-Karpathean Depression, USSR Stebnik-Kaloush	15,000 T (rough ore)	129	25
Moncton Basin, New Brunswick, Canada		182	70
New Mexico, Carlsbad and Paradox-Basin, USA	925	800[2]	33
Sergipe, Brasil	11	100	25
Congo-Brazzaville	40	0	0
Cataloneau Basin, Spain	360	100	21
Upper Rhine-Graben, France	300	217	20
Miocene, Sicily	155	30[4]	6
Zechstein-Yorkshire, U.K.	130	240[2]	60[2]
Zechstein-West-Germany	9,000	650	218[3]
Zechstein-East-Germany	9,000	730	245
	353,921	521,702[4]	37,100

[1] Solution mining.
[2] According to the U.S.-Bureau of Mines 1980, rsp. 1975.
[3] 119 Mill T MgO are to add as a by-product of kieseritic Hartsalz.
[4] The mineable reserves are coming from actual readings and are generally more certain than the in situ figures.
[5] A. A. Ivanov counts all potassium minerals (including carnallite).
The world reserves amounted *111 billion T K_2O* according to published statistics in 1973.

berg potash zone) only poor Stassfurt carnallitite and equally poor Hartsalz with 5–8% K_2O. It is not possible to transfer the productivity of the diapirs of the main Ronnenberg habitat, containing more than 7 million T K_2O each, as mentioned before, into the north. And even that would not be sufficient to come into the range of billions.

The *present mineable reserves* in West Germany, all necessary reductions considered, are *218 million T K_2O*; in addition, 119 million T MgO from kieserite as a by-product. The *in situ* reserves are all in all *about 650 million T K_2O*.

The Zechstein-Potash in the G.D.R. (East Germany). Currently the *mineable reserves are about 245 million T* and the *in situ* reserves come to *730 million T K_2O*, according to our own estimations in 1974, actualized through deductions of the tonnage mined in the meantime.

FINAL REMARK

The certain high reserves of various large depressions like the Prekaspian with 400,000 sq km and more than a thousand diapirs and brachy anticlines (according to A. A. Ivanov, 1969), the Iurassic deposit of Gourdak-Kugitang west of Samarkand, or the new recoveries of high-grade muriates in the central Siberean platform east of Krasnojarsk could not be dealt with because they have not yet been sufficiently described and defined numerically. The same is true for the Amazon basin.

They will have difficulty reaching international significance commercially because of their remote locations. The railroad distance from Krasnojarsk to Riga (Baltic Sea) is 4800 km, not much less to the Russian agricultural centers in the Ukraine and 6000 km to Vladivostock on the Pacific coast.

Medium-sized deposits with 12–14% K_2O in running mines near an area of high demand can be of higher value than very large ones with 20% K_2O and more, but located in a region like Central Siberia.

A table (VI) showing the world reserves of sylvinite and potash-sulfates, and some graphs are presented on the following pages.

ACKNOWLEDGMENTS

The writer wishes to thank the management of Kali und Salz AG, Kassel, for the friendly permission to use information obtained during the time he was with this company and to his former associates for their help in gathering literature.

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