PRACTICAL EXPERIENCE ANALYSIS: 
SUPERIMPOSED SEAMS SERIES MINING AT 
THE VERKHNEKAMSK POTASSIUM- 
MAGNESIUM SALTS DEPOSIT APPLYING 
ROOM-AND-PILLAR MINING METHOD 

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ABSTRACT

The paper describes the influence of geological conditions on parameters of mining methods and overburden deformations on Verkhnekamsk potash deposit, focusing on integrity of the hydraulic barrier during and after actual mining. We made an overview and analysis of mining experience on the deposit, the catastrophic accidents occurred on BKPRU-1, BKPRU-3 and SKRU-2 mines, behavior and subsidence of overburden at areas of accidents.

Key words: Mining, potash, mine flooding, hydraulic barrier, subsidence.

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1. INTRODUCTION

Evaporite ore mining has high risks of catastrophic flooding in case of hydraulic barrier failure during or after actual mining operations. The nature of rock salt, potash and other evaporities presumes rapid increase of water inflow even after a minor leakage in mined-out space due to dissolution of rocks. Therefore deformation of salt-bearing seams must be predicted and monitored while and after mining activities as mining induced stress and strain state is time-dependent and provides gradual adjustment of the seams. The main danger are the subvertical cracks that form in salt seams roof and cross the hydraulic barrier which substantiate room and pillar mining methods to be used in evaporite mines. Only when the thickness of the hydraulic barrier exceed such of the mined seam 40 times and more, as it is at Starobinsky deposit in Belorussia, long wall mining methods could be applied.
This paper examines the influence of geological conditions of Verkhnekams deposit on parameters of room and pillar mining method and behavior of undermined overburden to identify the factors which characterize flooding safety on all stages and after mining.

2. TYPICAL GEOLOGICAL FEATURES OF SEAM MINING AT THE VERKHNEKAMSK DEPOSIT

The Verkhnekamsk Deposit is located in Perm region, Russia and is one of the largest world deposits of potassium-magnesium salts (the total explored geological resources exceed 135 billion tons of sylvinites and carnallite ores). The Deposit has been under development since 1934, its industrial seams are: sylvinites ones - Kr.II, AB and Vs (V-seam of sylvinites composition), and Vc, which is V-seam of carnallite composition. Other promising seams include less thick sylvinites ones Kr.III and Kr.I.

The Deposit has accumulated an extensive experience of potassium salts extraction, both positive and negative. In total, the field had seven working mines. For instance, the SKRU-1 mine has been operating since 1934, and the newest BKPRU-4 mine since 1986. However, several mines were flooded: BKPRU-3 in 1986, after only 13 years of operation, BKPRU-1 after 64 years of operation, in 2006. In 2015 water broke through into the SKRU-2 mine shafts; but currently the water is being restrained.

The potash field at the Verkhnekamsk Deposit has an average thickness of about 72 m and an area of 3,680 km², it is located inside the borders of the salt bed; and can be traced 140 km meridionally and up to 42 km in width. The field is divided into two zones: the lower sylvinites zone, with four sylvinites seams (Kr.III, Kr.II, Kr.I and A), and the upper carnallite zone with nine seams (from B to K), which composition varies in certain areas from either carnallite rock or motley sylvinites to both varieties of the salts. The productive seams are separated from each other by rock salt layers; however, the B-seam lies directly on the A-seam.

Currently, of all carnallite seams only the V-seam is being developed. The Vc carnallite seam is developed at the SKRU-1 mines, used to be developed at BKPRU-1 and is going to be developed at BKPRU-2. The Vs-seam (of sylvinites composition) is being mined at SKRU-2 and SKRU-3 and is going to be mined at BKPRU-4.

The structure of the sylvinites bench includes three seams of red sylvinites (Kr.I, Kr.II, Kr.III) and the A-seam composed of banded sylvinites, above which lies the B-seam, the lowest one in the carnallite bench. However, 70% of the B-seam is mostley sylvinites [1]. In the usual course of mining these seams are extracted together and marked as the AB-seam. Above the B-seam, the cross-section of the carnallite bench shows eight more seams of carnallite rock (V-K). In some parts of the field above the B-seam the carnallite rocks are replaced by motley sylvinites.

The Kr.II-seam is the main productive seam, consisting of seven layers marked by ordinal numbers from top to bottom. Odd layers 1, 3, 5, 7 are composed of sylvinites, even layers 2, 4 and 6 are composed mainly of rock salt (halite).

The seams have a complex structure, irregular hypsometry and incidence angles varying from 0 to 15 degrees and more locally. The stability of roof rocks, gas ingress, as well as hypsometry ratings vary over the seams and mine fields.

The occurrence depth of the developed seams in the mine fields varies within the following limits: the V-seam 140-441 m, the AB-seam 146-451 m, the Kr.II-seam 158-461 m.
Details for the average thickness of the seams and KCl concentration, by the mines, are given in the table. The ranges of thicknesses of inter-layers in the main productive seams [1] are shown in the Figure 1.

**Table 1** The average thickness of the seams and the content of potassium chloride in them for the Verkhnekamskoye deposit [1].

<table>
<thead>
<tr>
<th>Mine fields</th>
<th>V</th>
<th>AB</th>
<th>Krasniy I</th>
<th>Krasniy II</th>
<th>Krasniy III</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKRU-1</td>
<td>4.7 m,</td>
<td>34.8 m, KCl, %</td>
<td>3.7 m,</td>
<td>34.1 m, KCl, %</td>
<td>1.4 m,</td>
</tr>
<tr>
<td>SKRU-2</td>
<td>4.4 m,</td>
<td>30.2 m, KCl, %</td>
<td>3.5 m,</td>
<td>33.4 m, KCl, %</td>
<td>1.1 m,</td>
</tr>
<tr>
<td>SKRU-3</td>
<td>3.4 m,</td>
<td>33.3 m, KCl, %</td>
<td>3.2 m,</td>
<td>32.8 m, KCl, %</td>
<td>1.0 m,</td>
</tr>
<tr>
<td>BKPRU-1</td>
<td>4.1 m,</td>
<td>34.8 m, KCl, %</td>
<td>3.6 m,</td>
<td>35.8 m, KCl, %</td>
<td>1.4 m,</td>
</tr>
<tr>
<td>BKPRU-2</td>
<td>-</td>
<td>-</td>
<td>2.1 m,</td>
<td>42.1 m, KCl, %</td>
<td>1.0 m,</td>
</tr>
<tr>
<td>BKPRU-3</td>
<td>-</td>
<td>-</td>
<td>3.2 m,</td>
<td>37.4 m, KCl, %</td>
<td>1.2 m,</td>
</tr>
<tr>
<td>BKPRU-4</td>
<td>2.6 m</td>
<td>28.8 m</td>
<td>2.8 m</td>
<td>42.0 m</td>
<td>1.2 m</td>
</tr>
</tbody>
</table>

**Figure 1** Generalized structural column of seams AB and Kr.II

The geological cross-section shows that above the developed seams there are anhydrous and waterproof rocks layers, and between the roof of the upper developed seam and the roof of the upper rock salt layer there is a hydraulic barrier (HB). The rocks of the mass make a natural barrier against water and brines penetrating from aquifers into the shafts with readily soluble ores. The choice of parameters for the applied mining methods and ways of rock pressure control directly rely upon the structure and properties of the rocks composing the mass.
The cross-section of the waterproof mass in the Verkhnekamsk Deposit shows that by the structure and composition of the rocks the mass has three well-marked parts:

- the lower (HB1), composed of alternating seams of potassium-magnesium salts and rock salt;
- the medium (HB2), composed of blanket rock salt;
- the upper (HB3), composed of regularly alternating seams of marls and rock salt.

The HB thickness above the upper developed seam, by the mines, is given in the Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Mine field</th>
<th>Upper seam</th>
<th>The thickness of the HB above the roof of the upper seam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>minimum</td>
</tr>
<tr>
<td>BKPRU-1</td>
<td>V</td>
<td>38,8</td>
</tr>
<tr>
<td>BKPRU-2</td>
<td>AB</td>
<td>57,7</td>
</tr>
<tr>
<td>BKPRU-3</td>
<td>AB</td>
<td>-</td>
</tr>
<tr>
<td>BKPRU-4</td>
<td>V</td>
<td>46,0</td>
</tr>
<tr>
<td>SKRU-1,2</td>
<td>V</td>
<td>24,0</td>
</tr>
<tr>
<td>SKRU-3</td>
<td>AB</td>
<td>13,5</td>
</tr>
</tbody>
</table>

Strength properties of the Verkhnekamsk rocks were investigated by A.A. Skochinsky Institute of Mining (IGD), Russian National Research Institute of Hydraulic Engineering (B.E. Vedeneev VNIIG), Kazakhstan Research Experimental Institute “Giprouglegormash”, the Mining Institute of the Ural Branch of the Russian Academy of Sciences and other institutions (Table 3). The developed mineral seams are heterogeneous in their structure and composition. Almost every inter-layer and seam has its own mineralogical composition, which results in a dramatic difference in physical-mechanical properties of salt rocks in the cross-section of the Verkhnekamsk deposit [4]. Apart from that, the properties of rocks fluctuate depending on the measuring method and the size of the samples.

### Table 3

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Conventions</th>
<th>AB</th>
<th>Kr.II</th>
<th>Rock salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Fortress by M.M. Protodiakonov</td>
<td>$f$, units</td>
<td>2-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive strength</td>
<td>$\sigma_c$, MPa</td>
<td>25,1</td>
<td>39,6</td>
<td>37,1</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>$\sigma_t$, MPa</td>
<td>0.27-0.43</td>
<td>0.61</td>
<td>0.46</td>
</tr>
<tr>
<td>Shear strength</td>
<td>$\sigma_{ab}$, MPa</td>
<td>2.0-2.5</td>
<td>2.0-3.5</td>
<td>2.4-5</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>$E$, MPa</td>
<td>22000</td>
<td>18800</td>
<td>-</td>
</tr>
<tr>
<td>Abrasiveness</td>
<td>$a$, mg</td>
<td>0.14-7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk mass of ore in the massif</td>
<td>$\gamma$, t/m$^3$</td>
<td>2,07</td>
<td>2,15</td>
<td></td>
</tr>
<tr>
<td>Angle of repose</td>
<td>$\alpha$, degrees</td>
<td>35-40</td>
<td>40-45</td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td>$P$, %</td>
<td>1-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density</td>
<td>$\gamma_b$, t/m$^3$</td>
<td>1.25-1.35</td>
<td>1.25-1.35</td>
<td>-</td>
</tr>
<tr>
<td>Coefficient of friction against steel</td>
<td>$K_f$, share</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle of internal friction</td>
<td>$\varphi$, degrees</td>
<td>20-30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The average rocks resistance to cutting is: for sylvinite - 522 kN/m, values ranging from 338 kN/m to 785 kN/m; for rock salt - 498 kN/m, values ranging from 381 kN/m to 634 kN/m [1].

Data analysis of the tests on rock specimens from the VerkhneKamsk Deposit made the Mining Institute of the Ural Branch of the Russian Academy of Sciences, confirmed that mechanical properties vary greatly depending on the composition and structure of the rocks. Moreover, the variation of physical-mechanical properties can be traced both vertically and horizontally (Figure 2) [5].

**Figure 2** Change in the compressive strength of rocks in the AB-seam within Solikamsk and Novosolikamsky sites; cell size 1 km2 [5]

The position of seams is almost horizontal, but is somewhat complicated by local folding.

The surface relief of the AB-seam at the BKPRU-2 mine is a good example of that (Figure 3). The size of the section shown in the figure is approximately 7700x7950 m.

**Figure 3** The surface relief of the AB-seam at the BKPRU-2 mine [6]
3. ANALYSIS OF PRACTICAL EXPERIENCE OF FIELD DEVELOPMENT

3.1. Features of Development of Verkhnekamsk Deposit conditioned by the peculiarities of the structure

A sufficiently large depth of gently sloping potash ores seams and the necessity to cross the aquifers by the shortest tracks compels to use vertical shafts in the center of the mine field in the Verkhnekamsk Deposit in the course of development.

Nowadays, the mine fields are divided into extraction panels, with a width of 400 meters and a length of 1.5 to 4 km.

A schematic diagram of the panel preparation of two adjacent seams Kr.II and AB is shown in the Figure 4.

**Figure 4** Scheme of panel preparation of two adjacent potash seams: 1 - the main field transport and conveyor drifts; 2 - panel field transport and conveyor drift; 3 - the main ventilation drifts in the Kr.II formation; 4 - the main ventilation drifts along the AB-seam; 5 - ventilation panel drifts along the layers; 6 - panel gangways; 7 - chambers; 8 - slope from the Kr.II formation to the AB-seam; 9 - slope from the field horizon to the Kr.II [1]

The panel routes are located perpendicular to the axes of the main seam folds, so that the axes of the rooms may coincide with the axes of the folds. This decreases losses during excavation, lessens dilution of the ore, makes delivery convenient, gives a possibility to use combined and self-propelled machines in the rooms, and ensures a better filling of the dead rooms.

The ore delivered from the faces of the rooms is transported by conveyors along the panel excavation routes to the ore-passing boreholes with a diameter of 300 mm. The boreholes are of a cluster type, i.e. serve a cluster of rooms and are drilled every 130-150 m. Belt conveyors are used in the main panel entries.

The main mining parameters, regulated in the "Guidelines for Mines Flooding Prevention and Control" [7] are:
• the width of the rooms;
• the width of the inter-passage pillars;
• extraction thickness of seams in the course of mining and estimated thickness of the pillars;
• estimated thickness of inter-seam crown pillars;
• the filling rate of the rooms and the filling time required to complete the operation.

These parameters play a key role in order to ensure local and regional safety of mining operations: preventing collapse of the roof in the rooms and inter-seam structures, collapse of the pillars, and preserving the waterproof mass. The choice of these parameters is ultimately based on mining and geological features of the developed sites, physical-mechanical properties of the ore and the enclosing rocks, stopping methods, and safety requirements for under-working at the ground facilities. The mine fields at the Verkhnekamsk Deposit are divided into zones that differ in terms of the mining safety measures. This is how to identify a seams-developing zone with its own set of parameters: check if there is any anomalous waterproof mass, the number of seams under development, their depth of occurrence, geological thickness of the seams and inter-seam structures. The contours of such zones rarely coincide with the boundaries of panels or blocks. For example, the oldest SKRU-1 mine has more than 200 zones, BKPRU-2 and BKPRU-4, where there was practically no blast-hole drilling, have more than 40 zones.

3.2. Influence of parameters of mining methods on current state of the underworked mass

Let us consider in more detail certain parameters of mining methods and the criteria that determine them.

The length of the rooms is the most constant mining parameter, and is generally equal to the width of the half-panel - 200 meters. When developing several seams, the rooms are strictly coaxial [8].

The width of the room is determined by the stability of its roof. A stable passage of the room is verified in the course of rooms inspection in the reports of specialized scientific institutions. In general, the width of the rooms, depending on the geological conditions, varies from 3 m in the areas with a poor-stable roof to 16 m in areas with a stable roof.

For instance, the carnallite V-seam development applies rooms with a width of up to 8.0 m and a height of up to 10.0 m, leaving the intervening pillars with a width of 18.0 m (BKPRU-1 mine) and 19.0 m (SKRU-1 mine).

The width of the inter-passage pillars, left for technological reasons to ensure efficient operations of the combined machines and increase the stability of the roof, is assumed to be 0.6-1.6 m.

The width of the intervening pillars in the developed areas of the Verkhnekamsk Deposit depends on the width of the room, thickness of the seam, composition and properties of the ore, depth of development, location of the pillars against the boundaries of the mine field, and any anomalous waterproof mass. Due to a wide range of geological and mining conditions, the width varies from 3 m to 18.0 m and in each case must be calculated individually [9].
By stability and the nature of deformation after development the pillars at the Verkhnekamsk Deposit can be divided into three types: rigid, relatively rigid and collapsible. The criterion how to distinguish one type from the other is the loading degree of the pillar - C. As a matter of fact, this criterion is the ratio of the load on the belt pillar to its load-bearing capacity. The calculation procedure expresses it in the following formula:

\[ C = \frac{\gamma H}{\sigma_S} \cdot \frac{a + b}{b}, \]

where \( \gamma \) - volume weight of rocks, \( N / m^3 \); \( H \) - depth of mining; \( \sigma_S \) - calculated strength of rocks, \( Pa \); \( a \) - width of the room, \( m \); \( b \) - width of the pillar, \( m \) [7].

The estimated strength \( \sigma_S \) depends on the weighted average tensile strength of the rocks composing the pillar and the form-factor, which is the ratio of the width of the pillar to its height. It means that an increase in the height of the pillar proportionally reduces the estimated strength, and the loading degree of the pillars also increases proportionally. In the course of usual development the height of the pillars depends on the thickness of the seam; however, destruction of the inter-seam structure during the development of the adjacent seams changes the loading degree by 2-4 times, depending on the geological conditions.

At the Verkhnekamsk Deposit they take two measures in order to maintain the stability of the inter-seam structure. Firstly, filling of the dead space, and secondly, artificial increase in the thickness due to reduction in the extractable thickness of the adjacent seams.

The pillars can deform in different ways, depending on the degree of their loading. For example, if the loading degree is \( 1 > C > 0.7 \), that is, collapsible pillars, and provided that the stability of the inter-seam structure is maintained, the rocks are only destroyed along the contour of the room, evenly filling the voids, while the pillars are flexibly deformed until the sides, roof and soil of the mine meet. The authors of the work [10] studied the developed space at the BKPRU-2 mine, and walked over the mines in order to analyze the conditions of the rock massif after the active deformation stage of the enclosing rocks and subsidence of the surface. In particular, photographs of the cross-sections of the rooms mined 30 years before the study (Figure 5) were taken.

![Figure 5](structure_of_newly_formed_man-made_sylvinite_seam.jpg)

**Figure 5** Structure of the newly formed man-made sylvinitic seam [10]

Rigid pillars with the loading degree \( C < 0.3 \) are considered as absolutely stable and are only subject to dying plastic deformations [7]. Relatively rigid pillars retain their stability for

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a period longer than the life of the mine, although accidents at BKPRU-1 in 2006 and SKRU-2 in 1995 occurred precisely at the sites with relatively rigid pillars.

The effect of the loading degree of the pillars on the deformation of the waterproof mass is estimated through the calculation of the bending of the waterproof layers:

\[ V = 0.9 \ k_{ext} \ m_{ext} w, \ m \]

where \( k_{ext} \) - extraction coefficient; \( m_{ext} \) - extracted capacity; \( w \) - backfill factor of the rooms.

The calculated values must not exceed admissible figures for, at least, layers of rock salt, lying in the upper 20 meters of the waterproof mass. The procedure to determine admissible bending is rather complicated, so in the example we will only give results of such calculation for a full section of the waterproof layers near the borehole #506 located in the central part of the mine BKPRU-4 (Table 3).

### Table 3 Hydraulic barrier Rock salt seams characteristics

<table>
<thead>
<tr>
<th>Hydraulic barrier</th>
<th>Seam index</th>
<th>Foot depth, m</th>
<th>Roof depth, m</th>
<th>Thickness, m</th>
<th>Depth above AB-seam roof, m</th>
<th>Layer number</th>
<th>Allowed deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>HB3</td>
<td>I</td>
<td>269.60</td>
<td>257.60</td>
<td>12.0</td>
<td>72.80</td>
<td>[1]</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>276.30</td>
<td>273.20</td>
<td>3.10</td>
<td>66.10</td>
<td>[2]</td>
<td>4.47</td>
</tr>
<tr>
<td>HB2</td>
<td>PKS4</td>
<td>282.18</td>
<td>277.10</td>
<td>5.08</td>
<td>60.22</td>
<td>[3]</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>PKS1</td>
<td>296.00</td>
<td>287.48</td>
<td>8.52</td>
<td>46.40</td>
<td>[5]</td>
<td>0.33</td>
</tr>
<tr>
<td>HB1</td>
<td>I-K</td>
<td>303.10</td>
<td>297.00</td>
<td>6.10</td>
<td>39.30</td>
<td>[6]</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Z-Z</td>
<td>306.10</td>
<td>304.45</td>
<td>1.65</td>
<td>36.30</td>
<td>[7]</td>
<td>5.44</td>
</tr>
<tr>
<td></td>
<td>ZH-Z</td>
<td>309.20</td>
<td>306.60</td>
<td>2.60</td>
<td>33.20</td>
<td>[8]</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>E-ZH</td>
<td>313.55</td>
<td>309.95</td>
<td>3.60</td>
<td>28.85</td>
<td>[9]</td>
<td>2.65</td>
</tr>
<tr>
<td></td>
<td>D-D</td>
<td>322.05</td>
<td>319.55</td>
<td>2.50</td>
<td>20.35</td>
<td>[10]</td>
<td>3.37</td>
</tr>
<tr>
<td></td>
<td>G-G</td>
<td>328.30</td>
<td>326.40</td>
<td>1.90</td>
<td>14.10</td>
<td>[11]</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>V-G</td>
<td>336.60</td>
<td>335.00</td>
<td>1.60</td>
<td>5.80</td>
<td>[12]</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>B-V</td>
<td>342.40</td>
<td>340.95</td>
<td>1.45</td>
<td>0.00</td>
<td>[13]</td>
<td>0.05</td>
</tr>
</tbody>
</table>

In general, the results correspond to modern ideas of how water-conducting cracks occur in the waterproof salt barrier describing, for example, in [11]. The authors identify three relevant criteria for tightness of the hydraulic protection layer:

- **Dilatancy (or shear stress) criterion.** Plastic shear deformation can lead to damage in the rock, associated with a volume increase (dilatancy) due to the formation of microcracks, which dramatically increase the permeability.

- **Tensile stress criterion.** Similar to shear stresses, tensile stresses above the tensile strength of the rock mass will lead to damage and the formation of cracks which can serve as fluid pathways.

- **Minimal stress (or frac) criterion.** If the minimal stress in the rock mass is lower than the fluid pressure, the fluid can force its way along discontinuities, on the microscale (grain boundaries) or the macroscale (bedding planes).
Moreover, the first two criteria are typical for the whole shift trough formed in the course of time and development, while the third criterion comes up at the boundaries of zones with different extraction parameters, especially for safety pillars of various purposes, when a zone of relative stretching forms in the marginal part of the trough. It should be noted that the Verkhnekamsk Deposit mines have lots of zones with different development parameters in terms of flood protection measures. For instance, at the SKRU-1 more than 200 zones that vary by geological and mining conditions have been identified within 80 years of development.

Based on the above, it is obvious that the best way of instrumental monitoring of the current state of the underworked mass is monitoring of subsidence of the surface. The results of monitoring can be interpolated to the waterproof mass. Also, the measurements of the mining contours divergence show a good correlation with subsidence of the surface [12], which can also be used to localize the waterproof mass zones with different development parameters. Further on, by using the data on real subsidence of the surface, it is possible to adjust numerical stress-strain models of the rock that give more reliable estimates of deformation and strain in the critical mining parameters and certain layers of the waterproof mass.

Undoubtedly, the fact that rates and values of subsidence at some sites of mine fields increase to the figures exceeding the estimated ones demands a more careful geological survey control and geo-mechanical support of mining operations. With regards to the continuity criteria considered above, high subsidence rates contribute a lot to destruction of individual layers of the waterproof mass, while a minimal stress criterion, on the contrary, requires a relatively constant bending of rock layers and hydrostatic pressure [13, 19].

**3.3. Assessment of the effect of subsidence rates on the probability of water and brine penetration into the mine**

Let us look into the negative Vernekamsk experience of determining the effect of subsidence rates on the probability of water and brine penetration into the mine.

![Figure 6](http://www.iaeme.com/IJCIET/index.asp) Part of the mininf field in wich brine inflows in roofs of workings were recorded

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In June 1986, the BKPRU-3 mine was flooded. This accident became one of the largest in the history of salt deposits development; since one of the world newest and most progressive mines was lost. The site of the accident developed only the KrII-seam, with thickness varying from 5 to 5.5 meters. The ore was crushed by combined machines, the width of the rooms $a = 5.3$ m, the width of the pillars $b = 3.8$ m, the depth of work was about 400-450 meters, the thickness of the waterproof mass above the top of the developed seam was about 100-110 meters. Under such conditions, the pillars are considered as collapsible, with $C > 0.7$. Initially water showed directly at the site under development in early January 1986 (Figure 6) [13].

The author [13] distinguishes three periods of the accident:

1) January 11 to January 15: relatively steep growth of discharge (from 10 to 30 m$^3$/h), abrupt drop of TDS in brines (from 370 to 343 g/dm$^3$), rapid increase of the contents of NaCl (from 25 to 160 g/dm$^3$) and S04 (from 0.5 to 1.6 g/dm$^3$) and decrease of MgCl 2 (from 270 to 11.5 g/dm$^3$), CaCl 2 (from 30 to 13 g/dm$^3$) and Br (from 4.2 to 0.9 g/dm$^3$).

2) January 16 to February 20-23: relatively slow growth of discharge (from 30 to 100 m$^3$/h), decrease of TDS (from 345 to 323 g/dm$^3$) and the content of MgCl 2 (from 115 to 25 g/dm$^3$), CaCl2 (from 13 to 2 g/dm$^3$), Br (from 0.9 to 0.3 g/dm$^3$) and increase of the content of NaCl (from 160 to 270 g/dm$^3$) and SO4 (from 1.6 to 3.9 g/dm$^3$)

3) February 21-24 to March 8: abrupt growth of discharge (from 100 to >350 m$^3$/h), fluctuating TDS and chemical composition.

On March 8-9, the accident went into a disastrous stage, with mineralization brine entering the mine at the rate of more than 5000 m$^3$/hour. At the time of the accident the volume of voids in the mine amounted to more than 15 million m$^3$ in total, which, apparently, were completely flooded. In the area of the initial leakage a sinkhole was formed on the surface with sizes approximately 70x45 meters, which subsequently increased to 140x210 m.

At the time of the accident, the subsidence of the underworked surface in the inner edge of the shift trough made 1.2 m with the maximum subsidence rate of 180 mm/month [14].

This accident was the first at the Verkhnekamsk Deposit and triggered a review of safe mining conditions while applying mining methods for collapsible pillars, it also facilitated a large-scale geophysical studies of the waterproof mass structure in order to identify its abnormal zones, for example, those composed of weakened rocks or with increased fracturing.

In 1995 there was a massive instantaneous collapse of the pillars in 25 rooms in the area of about 0.3 km$^2$ at the SKRU-2 mine. At the site of the accident, deposits were mined in 1976-1991 in the Kr.II and AB-seam, with loading degree of the pillars $C = 0.32 \div 0.36$. The total excavated thickness of KrII + AB amounted to 9 meters. The collapsed site adjoined the zone where the sylvinite V-seam was mined; with the total excavated thickness of three seams 14 meters. The depth of work was 330 meters; the thickness of the waterproof mass was about 105 meters. As a result of the bearing elements collapse, a shift trough formed almost instantaneously with maximum subsidence up to 4.5 meters, with open cracks on the surface along the edges of the trough (Figure 7). However, no water penetrated into the mine [11, 15].
In terms of mechanism of instantaneous subsidence of the surface, it is still impossible to explain the above-described event with subsidence to a depth of 4.5 meters on the area of 600x700 meters. Such subsidence should have caused a brittle destruction of the waterproof layers and a breakthrough of water into the mined area, but this never happened [16]. It is worth noting that the official version names the cause of the accident as a deep earthquake with a magnitude of 3.8, which dynamic load resulted in an instant destruction of inter-seam structure of the rooms and pillars.

After the collapse of 1995, the mine continued to function normally until 2014, when an increase in the brines flowing into the mine was detected in the collapse area. On 18.11.2014 on the inner edge of the shift trough a funnel with a diameter of 30-40 meters appeared on the surface. Scientists at the Leipzig Institute of Geomechanics predicted this event by a numerical model of the minimal stress criterion distribution. [11] Currently, the amount of flowing brines in the mine has been reduced and it continues to work under regular conditions.

In 2006 there was an accident flooding at the BKPRU-1 mine. At the site of the accident, the sylvinite seams AB and KrII and in the immediate vicinity the upper V-seam were mined by mechanical and drilling and blasting methods. The width of the rooms was 15-16 m, of the intervening pillars 10-11 m, with the excavated thickness of 6-7 m, the depth of the seams mining was 260-285 m. The AB-seam was worked out in 1965, Kr II - in 1977, the dead space was filled in 1996-1999, the filling was completed by 80%. In the emergency area there was a pillar of the geological exploration well # 17 [14]. Prior to the accident, the maximum subsidence of the surface in this area exceeded 3.7 m; the first significant subsidence was registered in 1993. Apparently, subsidence was caused by the deformation of the rooms and pillars. By the time of the accident the average subsidence rate was about 200 mm/year. The emergency water flow into the mine was recorded on October 17, 2006. By October 28, the flow of brines had increased to 1200 m3/hour, so brine pumping was ceased and the mining work stopped [14, 17].

Currently, special attention is focused on the areas with significant subsidence on a relatively small area: site 3 of the south-west panel at BKPRU-4, area of well # 69 at SKRU-1.
and 11 east panel at BKPRU-2. However, the increase of subsidence speed is only considered as an indicator of relatively high curvature and strain of the HB near a well pillar. [18]

4. CONCLUSIONS AND DISCUSSION

The overview catastrophic events occurred at Verkhnekaaskoe deposit show that HB failure could be predicted by monitoring of the ground subsidence in most of the cases. But the time before the actual inundandence is not enough to prevent the flooding by some changes in backfilling or mining parameters. If the parameters of room and pillar mining or backfilling do not suit geological conditions, as it was at SKRU-2, the failure of the pillars and the subsidence of the ground could be almost instantaneous, but it does not lead to HB failure at the moment. One of the possible reasons for this is that the extraction ratio (room and pillar width) should be designed so the HB could sustain the finite subsidence. But the curvature of the HB roof around the areas with different extraction ratio could lead to ground water perlocation in vertical direction and the decrease of the HB thickness which in a long-term period will cause mine flooding.

REFERENCES

Practical Experience Analysis: Superimposed Seams Series Mining at the Verkhnekamsk Potassium-Magnesium Salts Deposit Applying Room-and-Pillar Mining Method


