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ENVIRONMENTAL EFFICIENCY AND LEGAL POSSIBILITY OF MINERALIZED WATER DISPOSE IN THE SUPRASALT SEQUENCE OF THE VERKHNEKAMSKOE DEPOSIT

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The production of potash fertilizers at PJSC Uralkali is accompanied by the formation of excess solutions/brines, located on the sludge dump, where also comes water from salt brines and tailing piles, clay-salt slimes and atmospheric precipitation. After mechanical purification and reduction of the solutions/brines mineralization in the order of 5 million m^3/year are emitted into surface waters.

The studies carried out by Uralkali in 2000-2006 at the Verkhnekamskoe field, revealed an opportunity of underground disposal of mineralized brines/wastewater in the upper part of the salt-marl layer, directly overlapping the salt deposits and situated at depths not exceeding 300 m. Obtained results are confirmed by the state geological commission of the Federal Agency on Mineral Resources. The location of mineralized solutions in reservoir beds with an almost unlimited capacitive potential does not lead to the change in the hydrodynamic and hydrochemical regime of the underground hydrosphere and lessen the burden on the environment.

To implement underground disposal of mineralized process brines/wastewater, it is necessary to amend the «Concerning Subsurface Resources» Federal Law. Proposals of Uralkali to amend the «Concerning Subsurface Resources» Federal Law are supported by the Federal Agency for Mineral Resources and Federal Service for Supervision of Natural Resources.

Key words: Verkhnekamskoe salt deposit, production of potash fertilizers, excess solutions, wastewater, suprasalt sequence of rocks, underground collectors, «brine» horizon

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The problem of mineralized waters dispose on the PJSC Uralkali. PJSC Uralkali is one of the world's largest producers of potash fertilizers extracted from the Verkhnekamskoe salt deposit. Flotation and halurgical methods are used for potassium salts enrichment (processing) which are used at the enterprises of PJSC Uralkali.

The amount of mother-liquor formed during ore processing by the halurgical method exceeds the amount of the recycled solution used in the further production process. In this regard, the formed excess solutions are stored in sludge dumps. The potash ores enrichment (processing) by the above-mentioned methods is also accompanied by the formation of a large amount of solid halite waste, located on the ground surface as the salt tailing piles, clay-salt slurries, stored in sludge dumps.

The impact of atmospheric precipitation on the dump surface leads to the dissolution of halite waste. The formed mineralized wastewaters (brines) are collected in the salt brines, with further pumping into the sludge dumps. Thus, clay-salt sludge that comes into sludge dumps contains liquid phase (brines), solutions from enrichment halurgical plant, mineralized waters from salt brines, as well as atmospheric precipitation. All these solutions are moved to sediment ponds (water treatment facilities), where occurs purification from suspended solids and mineralization reduction.

Part of the water/solution from the sediment ponds is introduced into the process, and the excess part is discharged into water bodies in the form of waste (drainage) waters. There are developed regulations governing maximum permissible discharges for all waste (drainage) water releases, as well as obtained resolutions of the Ministry of Natural Resources and Environment of the Perm Krai and Kama Basin Water Establishment to use the water bodies to discharge waste (drainage) waters and Federal Supervisory Natural Resources Management Service permits to discharge pollutants.

The total volume of PJSC Uralkali waste (drainage) waters discharge in 2016 amounted to 5.4092 million m^3/year.

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The main pollutants in waste (drainage) waters are sodium (Na^+) and chlorides (Cl^-).

The ways of mineralized waters utilization. The issue of technogenic brines disposing, facing almost all potash enterprises, can be solved by evaporation, discharge into the surface hydrosphere (generally, sea basins) or by injection (placement) into underground reservoirs (lost circulation horizons).

Evaporation in open natural or artificial basins is possible in a sufficiently hot continental climate. In the natural conditions of the Verkhnekamsk region, when the amount of atmospheric precipitation exceeds 600 mm above evaporation (no more than 400 mm), this method is unacceptable. Evaporation of wastewaters and technological solutions using special equipment requires considerable energy costs, which leads to a significant increase in the cost of production and a decrease in its competitiveness in the market. Moreover, evaporation increases the volume of solid halite waste stored in the salt tailings piles, which makes its use ineffective from an environmental point of view.

At a number of potash enterprises, technogenic brines of potash production are discharged to the hydrosphere surface (usually sea basins). The discharge of technogenic brines into surface fresh watercourses, even in compliance with specified discharge standards, impacts the environment.

The underground disposal of potash production industrial wastewater in isolated underground aquifers is considered all over the world as the most effective way of technogenic brines dispose, which reduces the environmental impact and aims primarily at protecting underground and surface waters [2]. The greatest development of underground dispose of excess chlorinated sodium brines of potash production was obtained in Canada, Germany, and Belarus. Over 1.000 million cubic meters of brines were pumped into the reservoir beds during the operation of the underground discharge dumps.

The underground discharge is possible under the following conditions [1]:

– the presence of intake beds containing mineralized water, not suitable for water supply and not valuable for industrial and medicinal purposes;

– reliable isolation of reservoir bed and sufficient rocks transmissivity;

– chemical compatibility of waste brines with deposit waters and water-bearing rocks makes it possible to minimize the colmatation of rocks in the borehole zone of injection wells.

Geological and hydrogeological conditions of the suprasalt sequence at the Verkhnekamskoe salt deposit. The hydrogeologic section of the Verkhnekamskoe deposit is characterized by a general watercut of the suprasalt rocks complex (SSC). The water-bearing formations of the SSC (from the earth surface and up to the saliferous part of the salt-marl layer) are differentiated into primary terrigenous and carbonate deposits of Permian age with a predominant fracture permeability and the overlying Quaternary formations of various genesis with predominantly porous permeability.

The role of the underlying aquaclude is fulfilled by salt-bearing section. The potassium-magnesium salts pay bed is located inside salt-bearing section, which determines its absolute hydrogeological isolation in natural conditions.

The boundary between the saliferous and the suprasalt deposits is not stratigraphic, since it was formed as a result of the salt rocks leaching by super-saline groundwaters and constitutes so-called erosive «salt table» (top of the salt body).

Within the SSC deposit, there are aquifers, confined to Quaternary sediments, rocks of multicoloured (MC), terrigenous and carbonate (TC) and salt-marl (SM) sequences. The aquifers differ in permeability type and rocks water cut, the distribution of water levels of individual aquifers, the mineralization degree and the groundwater chemical composition.

Hydrogeological characteristics of aquifers are determined by the rocks occurrence depth, lithological composition, structural features, geological complexity, confinement to zones of various groundwater hydrodynamic and hydrochemical activity, and a basis for leaching (Fig.1).

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Anhydrous or poorly watered rock composing slopes of valleys, ravines and watershed spaces (clays, loams, sandy loams, fine-grained sands) are prevalent in *the Quaternary sediments*. More watery alluvial sands and gravels are sporadically developed in river valleys. The permeability of these rocks depends on the particle size distribution and ranges from 0.05 to 3.0 m/day. The chemical composition of groundwater is hydrocarbonate-calcium with mineralization of 0.2–0.3 g/l. The waters of the alluvial aquifer are weak-pressure, located near the earth's surface, at a depth of 3-5 m.

Multicoloured sediments of *the Sheshminsky aquifer* are characterized by the very variable water content. Fractured sandstones and mudstones are the water-bearing rocks. Specific borehole flow rates vary here from 0.046 to 0.400 l/s (the filtration coefficient does not exceed 0.85 m/day). Underground waters are characterized by a weak mineralization (0.2-0.3 g/l) and hydrocarbonate-sodium-calcium composition. The underground waters of this complex are used mainly for local water supply because of the relatively weak water content.

Water-bearing TC rocks of *the Upper Solikamsk aquifer* consist of fractured limestones, marls and sandstones. The highest water permeability of rocks of this sequence is noted in river valleys and in arches of anticlinal structures and the smallest is on the watersheds. Specific borehole flow rates vary here from 0.35 to 41.30 l/s. Rocks have a high degree of variability in filtration properties (the values of the filtration coefficient range from 0.021 to 88.900 m/day). Underground waters ubiquitously have a pressure reaching 45 m. The chemical composition of the horizon is characterized by a weak mineralization (up to 1 g/l) and hydrocarbonate-calcium composition, and in some cases by mineralization up to 3-4 g/l and sulfate-calcium composition.

Fissured marls are water-bearing rocks of the upper part of the salt-marly sequence (SM_2), *Lower Solikamsk aquifer*. The greatest abundance of water is noted in the upper part of the section (specific rates vary from 0.003 to 0.370 l/s). Middle and lower parts of the section with clay marls and calcareous clays are most often insignificantly waterlogged (specific borehole rates are from 0.0003 to 0.1100 l/s). Values of the filtration coefficient vary from 0.0002 to 1.9900 m/day with underground pressure head waters. Underground waters of the strata have mineralization up to 10 g/l and sulphate-calcium composition in the upper section, mineralization increases to 260 g/l with depth, the chemical composition changes to sodium chloride.

In the lower SM_2 part (on the border with the «salt table») a thin (first meters) brine horizon with salinity up to 300 g/l is traced.

Disposing of the mineralized waters in the rock beds: experimental test results. Studies conducted in 2000-2006 at the Verkhnekamskoye minefields showed the fundamental possibility of carrying out underground disposal of mineralized process brines/wastewater into rocks of the upper part of the salt-marl sequence, directly overlapping the salt-bearing sediments and lying at the depth of not more than 300 m [3, 4, 6].

In 2000-2004, test-investigation and observation wells were drilled and developed in the mine-field of the flooded BKPRU-3 mine. A set of works, including zonal and test pumping, test loading and pilot injection in the volume of about 260 thousand cubic meters of brines, was performed in these wells. It was determined that the absorbing horizon (reservoir bed) lies in the depth interval of 230-300 m and is characterized by the average transmissibility and permeability coefficients of at least 100 m^2/day and 2 m/day, respectively, with an average total thickness of about 65 m and a pressure conductivity coefficient of $6.0 \cdot 10^4$ to $1.4 \cdot 10^5$ m^2/day. The potential of the reservoir is estimated at a volume of not less than 15 million cubic meters with an effective crack formation criteria (porosity ratio) of 2.0-2.5 % and a net thickness of about 17 m. The average productivity of the absorbing wells was 40-50 m^3/h with the oil reservoir capacity of about 3000 m^3/day.

Materials of the geological and hydrogeological reasoning of potash production liquid process waste underground dispose underwent a State geological examination (Expert report № 1226 of 14.07.2006). According to the decision of the State Reserves Committee (SRC) of the Federal Agency on Mineral Resources (par. 2.1.1 of the report № 1226 of 14.07.2006), *the geological and hydrogeological modes of occurrence and the poro-perm properties of the water-bearing rocks of*

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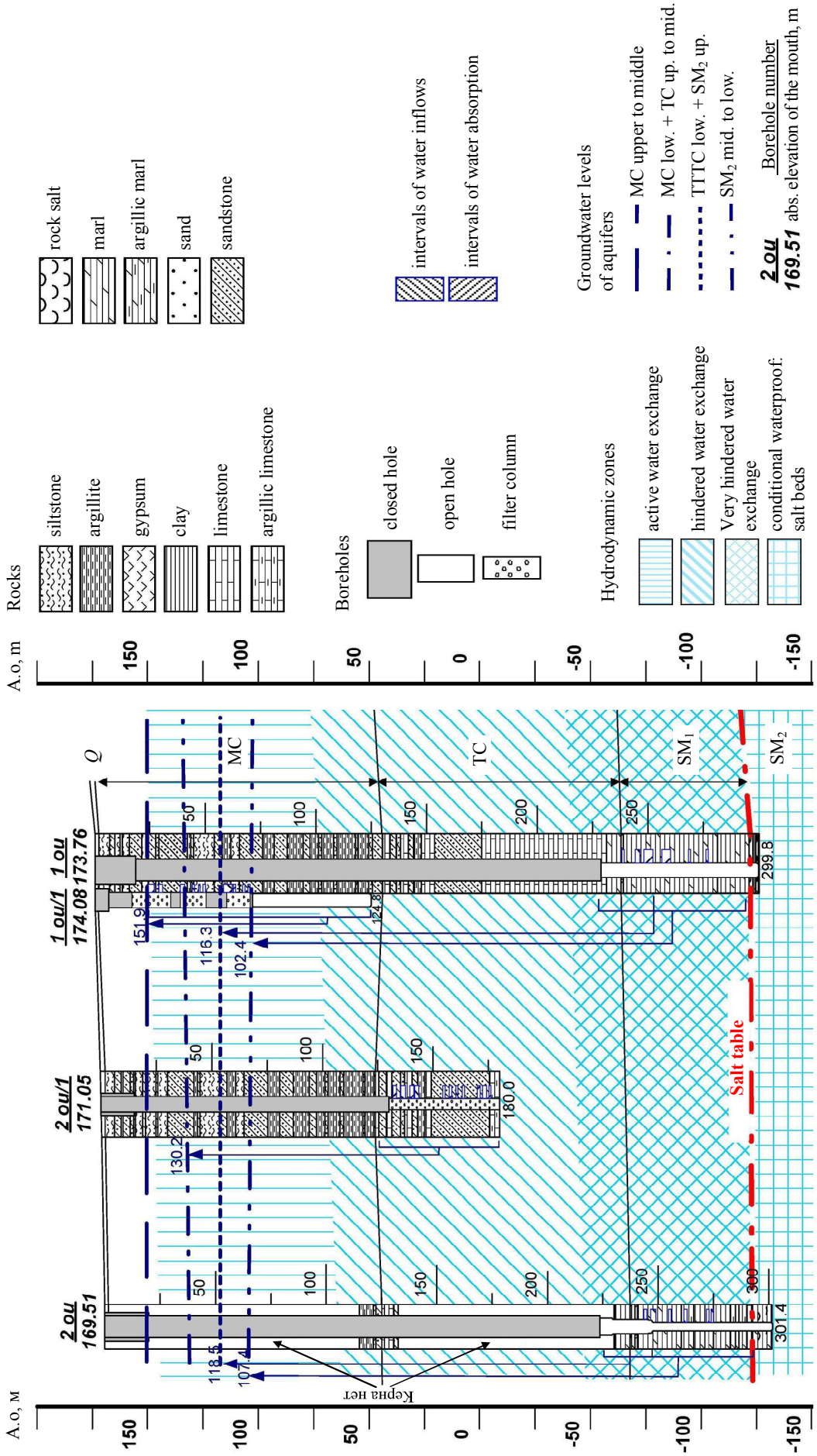

Fig.1. Schematic geological-hydrogeological section along the line of boreholes *2 ou – 2 ou/1 – 1 ou/1 – 1 ou*

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the lower part of the terrigenous and carbonate sequence and the upper layers of the salt-marl sequence ... allow using them as a reservoir for the cycling brines of potassium chloride production disposal.

In 2005-2006 field work was carried out to study the possibility of underground discharge of mineralized waters/brines of BKPRU-4 mine. Prospecting and observation wells were drilled near the northwestern boundary of the BKPRU-4 minefield, alongside the sludge dump, with the implementation of the comprehensive study, including the test brines injection of about 70,000 cubic meters. It is established that the absorbing horizon lies in the depth interval of 150-200 m and is characterized by the average transmissibility and permeability coefficients of at least 100 m^2/day and 2 m/day, respectively, with an average total thickness of about 50 m and a pressure conductivity coefficient of 10^5 to $4 \cdot 10^5$ m^2/day. The potential of the reservoir is estimated at a volume of not less than 12 million cubic meters with an effective crack formation criteria (porosity ratio) of ~ 2.7 % and a net thickness of about 15 m. The average productivity of the absorbing wells was 50 m^3/h with the oil reservoir capacity of about 3000 m^3/day. Materials of the geological and hydrogeological reasoning of commercial exploitation of the potash production liquid waste landfill at the Bygel-Troitsk area were subjected to state geological expertise underwent a State geological examination (Expert report № 2401 of 10.02.2011).

According to the decision of the State Reserves Committee (SRC) of the Federal Agency on Mineral Resources (par. 3.2 of the report № 1226 of 14.07.2006), *the geological and hydrogeological modes of occurrence and the poro-perm properties of the water-bearing rocks of the upper layers of the salt-marl sequence ... allow using them as a reservoir for the potash production brines disposal at the Bygel-Troitsk area.*

Thus, in the conditions of the Verkhnekamskoye saliferous basin, the dispose of mineralized waste (drainage) waters/brines is technically possible and environmentally effective in the rock beds lying above the salt deposit at a depth of 150-300 m below the Earth's surface and containing natural mineralized waters which chemical composition is identical to the injected solutions (Fig.2).The solutions dispose in reservoir beds with an unlimited capacitor potential does not lead to a change in the hydrodynamic and hydrochemical regime of the underground hydrosphere and, in principle reduces environmental burden.

The PJSC Uralkali proposals for changes and amendments to the legislation on mineral resources. It is necessary to obtain a special license to use the subsoil for the implementation of pumping (dispose) of waste and other waters as the excess brines in the rock beds within the Russian Federation.

At the same, the waste and other waters/brines injection activity in the Russian legislation on mineral resources is ambiguous. On the one hand, the Russian legislation on mineral resources provides for the use of subsoil both for the processing and consumer wastes disposal and for the maintenance of facilities of local and regional relevance, unrelated to the mineral production. On the other hand, there are unreasonable administrative barriers related to environmental protection, which preclude the injection (dispose) of waste and other water/brines in the rock beds [5].

Legislative bans on the waste disposal within the built-up areas and water protection zones, even with positive final expertise confirming the environmental and life safety, hinder license acquisition for the wastewater/brine disposal in the rock beds containing natural brines of the similar chemical composition. The water/brines dispose in the rock beds should obviously not have an environmental impact and can be carried out only if the geological survey is conducted and a positive Federal Agency on Mineral Resources experts' conclusion on the appropriateness of solicited area for the injection is obtained. Project documentation on the underground constructions for the subsoil waste water/brine injection is approved in accordance with the established procedure upon the positive final expertise of the RF State Expert Evaluation Department, during which its compliance with environmental protection requirements is verified.

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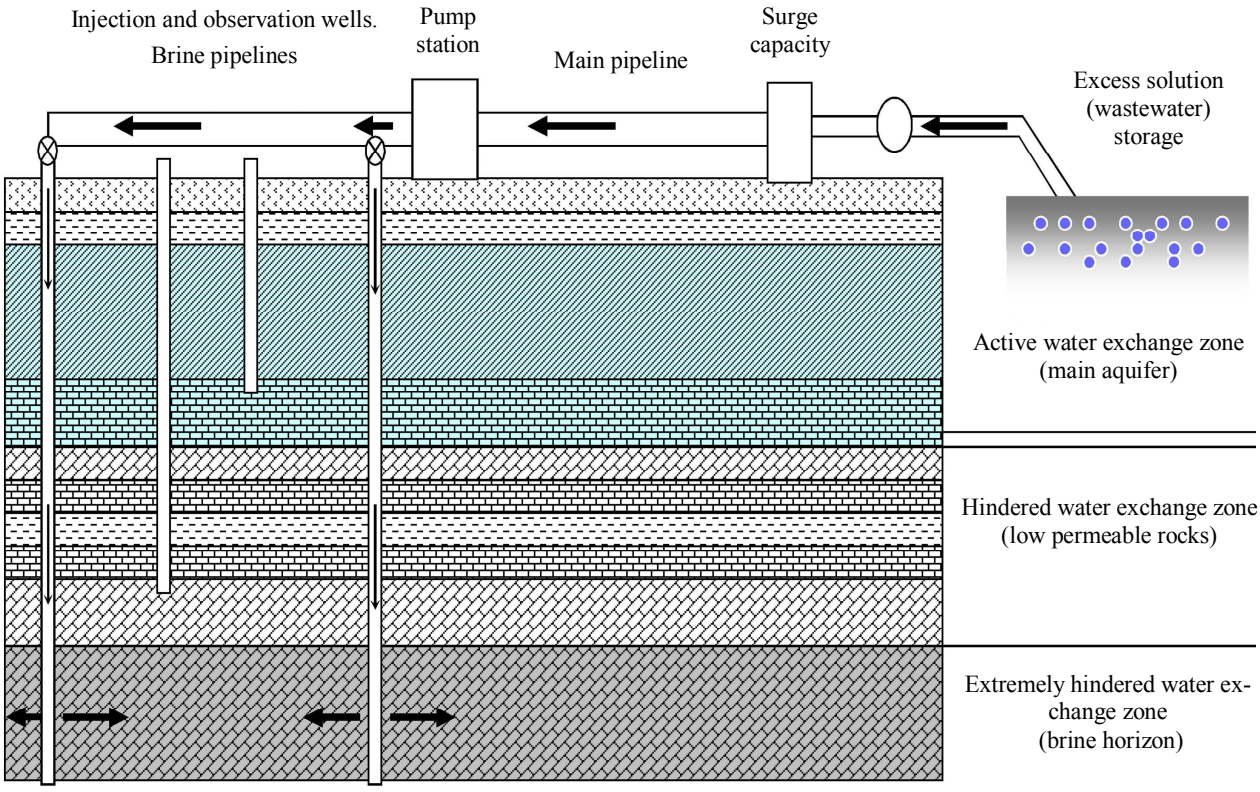

Fig.2. Basic scheme of excess brines (wastewaters) underground discharge into an isolated brine horizon of the supersalt rocks complex

There is a gap in the RF legislation on mineral resources, which prevents obtaining a license to use a subsurface site of local significance for the purposes of construction and operation of underground structures of local and regional importance that are not related to the mineral production. Article 10.1 of the legislation on mineral resources does not define an authority authorized to issue a license for geological exploration of subsurface sites of local significance for the purposes of construction and operation of underground structures that are not related to the mineral production. At the same time, this type of subsoil usage is provided in article 6 of the legislation on mineral resources. An additional point is that article 29 of the same law requires a geological survey and state expertise of geological information of subsurface sites suitable for the construction and operation of underground structures that are not related to the mineral production, before making these subsurface sites available for construction and operation of such structures.

Considering the above, PJSC Uralkali initiated legislation. It is proposed to introduce the following amendments to the RF legislation on mineral resources:

a) establish a new type of subsoil usage: dispose in the rock beds waste or other waters formed in the solid mineral deposits production, primary processing, mining or primary processing wastes handling;

b) provide a right to dispose wastewater or other water formed during the extraction of solid minerals, their primary processing or management of waste from mining or primary processing of solid minerals in rock stratum within the limits of the granted allotments and (or) geological areas on the basis of the approved technical design to mineral resource license holders who carries out exploration or extraction of solid minerals or who conducts, geological study, exploration and production of solid minerals under a combined license, or who performs primary processing, or handling of waste from mining or primary processing of solid minerals;

c) to supplement paragraph 6 of Article 10.1 of the RF legislation on mineral resources with the following paragraph (on the grant of decision-making authority to the executive branch of the constituent entities of the Russian Federation): *on granting the right to use a subsoil area of local*

significance for geological study and assessing the suitability of a subsoil plot for the construction and operation of underground facilities of local and regional importance, not related to the extraction of minerals.

These initiatives of PJSC Uralkali were fully supported by the Federal Agency for Mineral Resources of the Russian Federation, agreed with the Federal Service for Supervision of Natural Resources and are currently under consideration by the Ministry of Natural Resources and Environment of the Russian Federation.

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