Hydrogeological conditions and environmental hazard of salt dumps with special reference to potassium salt deposits in Vierchniekamsk, the Middle Ural Mountains, Russia

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Abstract: In the areas where potassium salt occurs (Soligorsk, Vierchnikamsk, Saskatchewan and others) hard halite waste material from enrichment plants is deposited on the earth surface. These dumps are from 50 to 80 meters high, their surface reaches tens of hectares and their volume - hundred millions of cubic meters. As a result of atmospheric precipitation and moisture action, intensive karstic processes develop on the surface and inside the salt dumps. Brines of diversified origin (from squeezing out during dumps consolidation, secondary ones of karstic origin and from atmospheric moisture condensation) produced in these processes migrate inside dump massifs towards the slope bases. They partly infiltrate into the underlying rocks causing contamination of underground water. Hydrodynamic zones are formed inside the dumps: of surface water run-off, of aeration and of horizontal circulation. Chemical denudation of dump surface reaches from 20 to 50 mm per year. Contamination of rocks and underground water by salt mining wastes creates serious economic and ecological problems. Salty zones around the dumps elongate in the direction of groundwater flow. Surface water salinity rises. Transformation of natural complexes towards more alkaline variety takes place in dumps vicinity.

1 INTRODUCTION

In the area of the Vierchniekamsk potassium salt deposits (the Ural Mountains, Russia) waste material from enrichment plants is deposited on the earth surface (Photo 1). Numerous dumps are from 50 to 80 meters high, their surface reaches tens of hectares and their volume is hundred millions of cubic meters. Intensive karstic processes have developed inside salt dump massifs as a result of climatic factors influence (Andrejchuk, 1989). Brines of diversified origin produced in these processes percolate vertically towards the dump base and migrate horizontally towards the slope base. These processes create the serious economical and ecological problems.

2 WASTE MATERIAL COMPOSITION AND MOISTURE

The hard salt waste material consists of salt rock chips, silty substance flakes and inclusions from salt deposit. This waste material consits of NaCl - 95.0%, KCl - 1.5-2.0%, $MgCl_2$ - 0.1%, $CaSO_4$ - 2.0% and insoluble parts 1-1.5%. Its grain size composition depends on the degree of rock disintegration. Particle size and shape change after dumping. As a result of waste material gravitational consolidation and salt recrystallization, the integration and hardening of the material take place. Freshly dumped material is bright and mottled. In time, it is

Photo 1 Salt dump view

getting dark as a result of the dissolution of bright salt grains and the accumulation of dark silty parts. Fresh hard salt waste contains original liquid in the amount from 8 to 22% of weight. It depends on flotation processes. In respect to its chemical composition it is NaCl brine with mineralization from 360 to 375 g/l (Klementiev et al., 1973).

3 GRAVITATIONAL WASTE CONSOLIDATION

As a result of consolidation, waste material is subjected to cementation and transformatiom from fluid mass into thick polimineral rock of grainy structure. The porosity of freshly dumped material is from 40 to 45% and at the dump base from 0 to 2%. During drifting at the old salt dump base (of Soligorsk mine „Bielarus") it was observed the waste material became a partly consolidated rock impermeable to brines. On the base of experimental investigation, Klementiev (et al., 1973) stated that the solid impermeable to brines zone at the salty dump base is formed as a result of following processes: dehydration of waste material under influence of gravitation, waste thickening due to its own weight as well as plastic deformation and physico-chemical processes in porous solutions (growth of crystallic hydrates during brine thickening and temperature changes, partial change of free water into chemically bounded one). As a result of these processes in the horizontal profile of the salty dumps three rock zones of different permeability are formed: a) poorly b) moderately and c) well consoli-dated. Their engineering geological properties are as follows: a) γ_0 = 1.6 g/m^3, M to 15%, k_p from 0.5 to tens m/d; b) γ_0 = 1.76-1.85 g/cm^3, M 5 to 10%, k_p = 0.5 to 0.005 cm/d; c) γ_0 = 1.85 to 2.0 g/cm^3, M to 3.5%, k_p = 0; where: γ_0 - rock bulk density, M - rock moisture, k_p - vertical hydraulic conductivity.

The layer developed at the salty dump base impermeable to brines protects underlying soil and groundwater from brines percolation (Klementiev et al., 1973).

As a result of rock condensation, original level of dump becomes lowered of about 15 do 20%. The most intensive consolidation takes place in the first year and from the second one the dynamics of this process becomes slower. The evolutional development of geomorphological processes (banks squeezed outside of the dump outline) depends on fresh material delivery, natural thickening and differences in properties of material deposited in different parts of dump. It causes formation of disastrous deformations (landslides of the volume from 100 thousand to 800 thousand of cubic meters).

4 BRINES ORIGIN

The dumps contain brines of different origin. This includes brines from squeezing, secondary ones and of condesation origin.

The brines from squeezeng are sqeezed out from freshly dumped mass in the process of its thickening. This process is the most intensive in the first months after dumping. Later dynamics of this process is slower what is connected with material dehydration and dissolved salts crystallization. As overburden weight is bigger more of squeezed brines is produced (Figure 1). From 1 m^3 of salty dump 0.89 m^3 of brines with mineralization of 300 g/dm^3 is squeezed out. Brines from squeezing occur in the area of direct dumping (Photo 2). When thickness of the freshly dumped layer is high, the brines percolate fast towards the dump isolation shield.

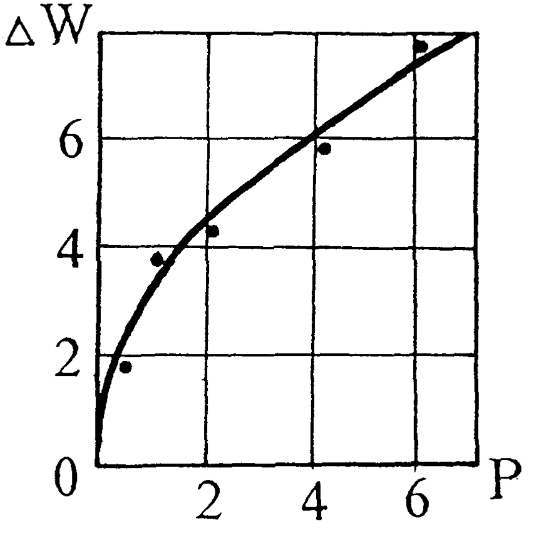

Figure 1 The relation of dumped rock moisture losses to pressure gradient on the base of experimental investigation
P - load kg/cm^2, W - moisture losses % (after Klementiev et al., 1973)

Secondary brines of karstic origin are produced by dissolution of soluble salts with atmospheric water. Their amount is calculated taking into account amount of the atmospheric precipitation and evapotranspiration from the salty dump (Vostriecov, 1984). For Bereznik area, the average annual amount of precipitation is 695 mm and evapotranspiration according to Rotkin and Aleksiejenko (1976) and Vostriecov (1984) is from 150 to 180 mm per year. The salty dump gets effectively from 515 to 545 mm of water which is from 74 to 79% of annual precipitation. Atmospheric water becomes saturated in the dump. During this process the volume of the secondary brines is enlarged of about 25% what is approximately equal to the volume of evaporated water. It can be assumed that the amount of the secondary brines in the salty dumps of Bereznik area is the same as the volume of the atmospheric precipitation in the area (515 to 545 mm per year).

The brines of consolidation origin distinguished by Rotkin and Aleksiejenko (1976) are formed by condensation of atmospheric moisture when the air temperature and misture fluctuate. Vostriecov (1989) states that the whole process „condensation - additional evapotranspiration" is fully determined by the amount of the average annual evapotranspiration similarly like conditions of alternate condensation or evaporation from the dump.

Photo 2 Salt lakes formed by squeezed brines at the salt dump base

5 CIRCULATION, HYDRODYNAMIC ZONATION AND BRINES CHEMISTRY

Granularity, fissurity and original softness of the material influence high permeability of dumps down to a considerable depth. A specific „infiltrational - corrosive" karstic relief is formed on the dump surface. It is different from the corrosive relief of impermeable natural surface of salty rock outcrops (Andrejchuk, 1989). Water permeability, high solubility of dumped material, presence of insoluble admixtures and diversification of dump material determine conditions of atmospheric precipitation percolation and formation of hydrodynamic zones. These zones are as follows: of surface water flow, of aeration and of horizontal circulation (Figure 2).

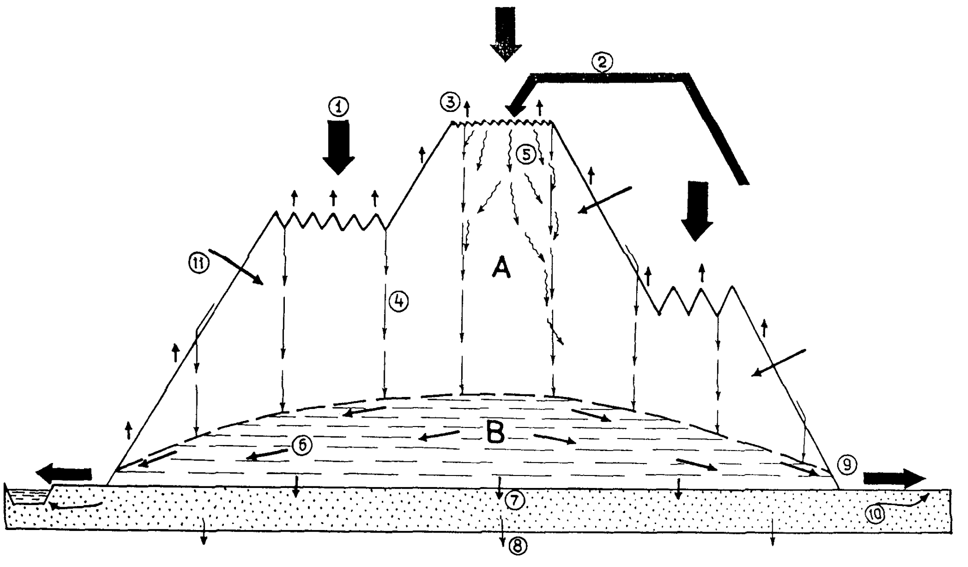

Figure 2 Salt dump hydrodynamical model and water balance elements:
A - infiltration zone, B - horizontal circulation zone, 1 - atmospheric precipitation, 2 - influence of freshly dumped waste material moisture, 3 - evapotranspiration, 4 - infiltration of atmospheric precipitation, 5 -precipitation of squeezed brines, 6 - brines flow directions, 7 - brines infiltration into dump basement, 8 - brines infiltration to groundwater, 9 - salty springs on surface, 10 - outflow to the surface of salty free water

Aeration zone is the largest part of the dump vertical profile. It shows high permeability, mainly in the upper karstic part. It can be divided into two sub-zones: of dissolved substances and insoluble admixtures vertical movement (of the thickness from 2 to 7 meters) and of insoluble material accumulation. The latter forms discontinuous layer of small tkicness rich in silty substance. It is an isolating layer. Part of the atmospheric precipitation percolating into the dump flows inside it paralllelly to the slope base. In the slope parts of the dump at the depth of 0 - 5 cm from the surface, a dense salty layer („peel") about 1 cm thick is formed as a result of evaporation. This aeration zone belongs to moderately condensed rocks where vertical filtration velocity is from 0.5 to 0.005 cm per day. The diversification in environmental permeability is connected with karst development. In the upper part of the dump from 1 to 10 m thick, rain drops penetrate directly through karstic openings: sink-holes, cones and downdrafts in a few second time. Also the rest of the moisture run downwards fast along vertical walls of the karstic forms. Moisture stops at the accumulation subzone formed by insoluble silty material and it partly evaporates. In the parts of the dump where fresh waste material is absent and the dump surface is of karstic character, accumulation subzone of insoluble material forms evapotranspirational barrier for atmospheric precipitation. As a result of this process, snow-white salty efflorence can be observed on the karstic walls which contrast with dark-grey background of the waste material.

Horizontal circulation zone (saturated with brines) occurs in the bottom parts of the dump. This zone is formed when very thickened rock impermeable for brines occurs in the salty dump basement. Thickness of brine saturated zone reaches from 20 to 40% of the total height of the salt dump. Brines circulate in the fresh dump towards dump boundaries with velocity of 1 - 2 meters per day. They are drained as effusions. Later on drainage from the saturation zone is concentrated in numerous underground channels from which brines flow out at the dump bottom as springs (Photo 3). Velocity of brines flow in the karstic channels is from 0.1 to 0.5 meters per second. Springs output changes from 0.1 to more than 5.0 litre per second. In places where springs flow out on the surface, the specific salty barriers and „salt snow" deposits are formed (Photo 4). In caverns salt aggregates can be observed. There are also many dripstone forms of the secondary deposits leaching.

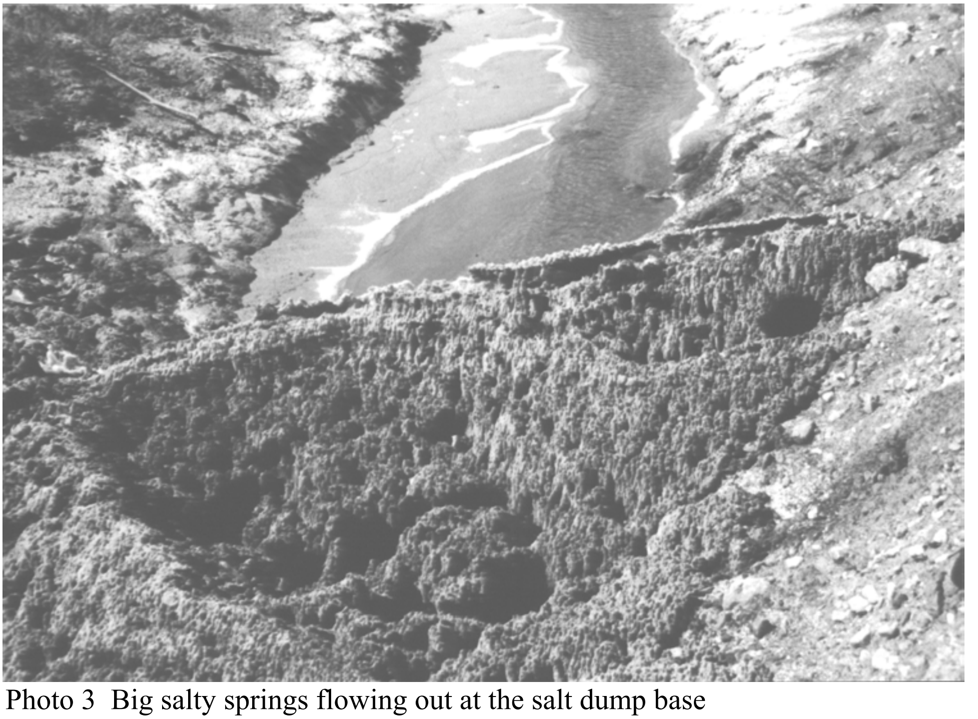

Photo 3 Big salty springs flowing out at the salt dump base

Photo 4 Salt deposits in places of outflow and evaporation on brine surface

The problem of brines percolation into underlying deposits is interesting considering the occurence of strongly thickened impermeable rocks in the dump basement. Maathius and Kamp (1983) show lack of infiltration from salt dumps into the underlying rocks in Saskatchewan area. According to other authors (Klementiev et al., 1973, Rotkin, Aleksiejenko, 1976, Vostriecov, 1984, 1989) such infiltration occurs and it is a few milimeters per day. The velocity of brines infiltration to underlying layers depends on permeability of these layers and occurence or absence of artificial isolating barrier (silty layer or polyethylene foil) on the basement topographic profile. According to Vostriecov, in the Vierchniekamsk deposit dump area infiltration intensity into salt dumps basement may be 3 to 4 thousands of cubic meters per year from the area of 1 ha or hundreds thousands of cubic meters within the whole surface of the dumps.

6 DUMPS CHEMICAL DENUDATION

Equation of the total annual water-salt balance of the salt dump can be determined as follows:

$$V_{tot} = V_1 + V_2 + V_3 - V_4 - V_5 - V_6 \ \ [m^3/y]$$

where: V - liquid amount: tot - in the salt dump, 1 - collected from dumped barren rocks, 2 - from atmospheric precipitation, 3 - of condesation origin, 4 – amount of evaporating liquid, 5 - flowing out as springs, 6 - percolating into basement of salt dump.

After determination of liquid amount and water mineralization at the input and output of the salt dump, the amount of soluble compounds outflow can be calculated according to the dump size. Most of them is washed out from the salt dump in karstic spring waters, as squeezed brines forming salt lakes along the dump outline and also as brines infiltrating into the dump basement. In all cases, water mineralization exceeds 300 g/dm^3. Small amount of salt load penetrates to the dump basement as a result of molecular diffusion. Tens and thousands of salt tons are washed out of the dumps as liquid during a year. Interrelations among dissolved components of the dumps as a result of squeezing, dissolution or dissolution from condensation are differentiated. During the dumping of fresh waste material which contains loose moist material, the main part of the carried out salt loads is connected with squeezed brines. For example Kolpasznikov et al. (1970) calculated amount of salt loads carried out from a salt dump to the underground water for a 5-year-old dump of the area of 60 hectares as follows:

$$Q_s = \frac{Q_{tw} \times \delta W_r \times M_r}{\gamma_r} = \frac{18.5 \times 10^6 \times 0.08 \times 0.3}{1.1} = 4 \times 10^5 \ \mathrm{t}$$

where: Q_{tw} - amount of dumped compact waste material = 18,5 x 10^6 t, δW_r - amount of moisture equal to losses of brine infiltration = 0,08, M_r - brine mineralization = 0.3 t/m^3, γ_r - brine bulk density = 1.1 t/m^3.

Amount of permanent annual outflow of salt load calculated for a surface unit is 1345 t/ha. This amount is higher than the one calculated for molecular diffusion process (322 t of salt load per 1 ha annually) and dissolved with atmospheric precipitation (600 t/ha annually). When the dump is some scores years old, the karstic processes play the main part in the outflow of the dissolved compact components. Such dumps and also older parts of the operating dumps form original karstic massifs with specific water circulation and characteristic surface morphologic - genetic complex and underground karstic forms. After time when insoluble material is accumulated inside the dump, intensity of karstic processes is decreases.

7 ECOLOGICAL PROBLEMS

Salt dissolution and transportation outside the dumps creates a very serious problem. This process causes development of the salted zone elongated towards the direction of underground water flow. Salt loads carried out of dumps become larger as karstic processes develope. In depressions located in the vicinity of the dump bases, salt lakes are formed where salt precipitatation takes place. Mineralization of surface water increases (Photo 5). On their banks, the forests become destroyed and soils are getting salty and degraded by disarrangement of their structure, changes of absorption complex and increase of erosive earth flow. Salt dumps influence on soils and vegetation takes place by the

Photo 5 Natural surface water basin poisoned with brines and destroyed forest on its banks

emission of salt particles blown by the wind and carried on a long distance. Transformation of natural complexes towards more alkaline variety takes place in dumps vicinity. Problems of salt dump karst, mineralization of surface and underground waters have to be solved in a complex way. The most effective method is filling of the exploited underground excavations with rocks deposited in dumps and exploitation of valuable useful minerals from the dumps.

REFERENCES

Andrejchuk V., 1989. Problems of salty dumps karst (in Russian). Karst Altaje-Sajanskoj gornoj oblasti i sopredelenych gornych stron. Barnal.

Klementiev V.P., Jeremienko J.P., Kolpasznikov G.A., 1973. Salty wastes consolidation as index of groundwater protection against percolation of brines into them (in Russian). DAN BSSR, T. HUP, No 3.

Kolpasznikov G.V., Klementiev V.P., Jeremienko J.P., 1970. Processes of rocks and groundwater salinization with compact wastes from potassium salt enrichment plants in Soligorsk area (in Russian). DAN AN SSR, T. H1U, No 5.

Maathius H., Kamp G. van der, 1983. Influence of a salt tailings pile on ground-water flow: a case history in Saskatchewan, Canada. *Potash Technol. Proc. 1st Int. Conf.* Saskatoon, Oct. 3-4, 1983, Toronto e.a.

Rotkin S.M., Aleksejenko J.J., 1976. Results of salty dumps investigations (in Russian). *Gidrogeologia i ochrana niedr pri razrabotkie solianych miestorozdienij.* L.: WNIIG.

Vostriecov S.P., 1984. Determination of brines run-off from potassium salt enrichment plants salty dumps (in Russian). Razrabotka zamknutych cyklov vodopolzoivanija na predprijatach Ministerstva po proizvodstvu mineralnych udobrienij. Czerkasy.

Vostriecov S.P., 1989. Calculation of infiltration into salty dumps (in Russian). *Voprosy prirody rajonov kalijnych predprijatij.* L.: WNIIG.

Warunki hydrogeologiczne i zagrożenie środowiska przez składowiska soli ze szczególnym uwzględnieniem złóż soli potasowej w Vierchniekamsku, środkowy Ural, Rosja

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Streszczenie: Na obszarze eksploatacji soli potasowej (Soligorsk, Vierchnikamsk, Saskatchewan i inne) na powierzchni składowana jest jako materiał odpadowy twarda sól kamienna z zakładów uzdatniania . Hałdy mają wysokość 50-80 m, zaś ich powierzchnia sięga dziesiątków hektarów, a ich objętość – setek milionów m^3. W wyniku oddziaływania opadów atmosferycznych na powierzchni oraz wewnątrz hałdy zachodzą intensywne zjawiska krasowe. Wytworzone solanki migrują wewnątrz masywu hałdy w kierunku podstawy zbocza. W zasięgu hałdy formują się strefy spływu oraz przepływu solanek. Denudacja chemiczna powierzchni hałdy sięga 20-50 mm na rok. Skażenie skał i wód gruntowych odpadami poeksploatacyjnymi stwarza poważne problemy natury ekonomicznej i ekologicznej. Strefy zasolenia środowiska wokół hałd zwiększają się w kierunku przepływu wód gruntowych. Zwiększa się zasolenie wód powierzchniowych. W sąsiedztwie hałdy zachodzi transformacja naturalnych kompleksów roślinnych w bardziej alkaliczne.