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Wind and water erosion of waste heaps at concentration plants for potassium production

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ABSTRACT As part of the refining process used in the potassium industry, huge areas of salt dumps are formed. This is a study of the rates of fluvial and aeolian erosion of salt dumps in Byelorussia. The dumps lithify relatively quickly but infiltration is still rapid at their surface; leaching results in a variety of karst features which help to create a very distinctive topography. The brines which emerge from springs at the periphery of the dumps can produce ruined agricultural soils and polluted groundwater. Remedies are listed.

Erosion par le vent et l'eau d'amas de déchets au voisinage d'usines de concentration pour la production de potasse
RESUME A la suite du processus de raffinage utilisé dans l'industrie du potassium, des zones immenses ont été couvertes de tas de sel. On présente ici une étude du taux d'érosion fluviale et éolienne de ces tas de sel en Byelorussie. Ces tas se pétrifient relativement vite mais l'infiltration est encore rapide près de leur surface; le lessivage de ces amas de sel conduit à une grande variété de caractéristiques karstiques qui créent une topographie très particulière. Les saumures qui apparaissent par des sources à la périphérie de ces tas de sels peuvent provoquer la ruine des sols au point de vue de l'agriculture et polluer les eaux souterraines. On énumére les méthodes pouvant remédier à cette situation.

INTRODUCTION

In many countries of the world man's influence on natural landscapes is increasing as the result of industrialization. The greatest changes of the surface relief are caused by mineral exploitation, mainly as a result of the stowage of waste and dumps of mining products. They cover hundreds of thousands of hectares of once fertile lands. One result is air, water and soil pollution. The wastes of the mining/chemical industry are especially dangerous for the purity of the biosphere; in most cases they contain substances toxic for flora and fauna.

This papers considers the erosion processes which act on the waste heaps at concentration plants of the Byelorussian potassium mining and processing industry.

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After extraction and concentration of the local Starobynsky silvinite rocks there are many salt by-products. These are stored in dumps 60-80 m high. Hard halite wastes which form the major salt dumps initially present a friable mass with a moisture content up to 10-12%. Residual solutions (brine) have a mineralization approximating 340-360 g l^{-1}; their composition is predominantly sodium chloride. Their mechanical composition is medium and mixed-grained sand with the following grain size distribution:

>1.0 mm	1.0-1.5%
1.0-0.50 mm	33-35%
0.50-0.25 mm	28-30%
0.25-0.10 mm	15-17%
0.10-0.005 mm	13-15%
<0.005 mm	4.5%

The chemical composition of the deposits is determined by the chemical composition of extracted silvinite ore. The content of halite (NaCl) in the salt dumps reaches 91-92%; KCl ranges between 2 and 4%. The insoluble residuum is determined by the admixture of halopelite: 3-4%. There are negligible quantities of calcium chloride, manganese chloride, carbonate, sulphate and bromine. The water insoluble residuum consists of aluminosilicate clayey minerals (kaolinite, hydromica, etc.). Waste storage results in a typical alpine relief with the V-shaped depressions between the ridges reaching 5-8 m.

Field experiments using boreholes, adits and special drainage devices, as well as studies of hydro-physical and mechanical characteristics of wastes have made it possible to identify the processes of filtration, consolidation and solidification. These take place in salt dumps under the influence of differential loads and erosion processes.

PROCESSES OPERATING ON THE WASTE DUMPS

After dumping, redistribution of the liquid phase (residual brines) in the material takes place due to the influence of overlying layers. This results in the formation of an aquifer which is drained by numerous springs at the bottom of the dump. Recharge of the brine occurs as a result of atmospheric precipitation and vapour condensation.

Consolidation of wastes under their own weight and physico-chemical processes taking place in pore solution (precipitation of solutes when brine density increases and when temperature conditions change, etc.), both bring about a zonation of the dumps with depth:

(a) the upper zone of slightly thickened wastes with a density of 1.6 g cm^{-3}, porosity up to 30-35% and filtration coefficient up to several dozens of metres per day;

(b) the middle zone of moderately compressed wastes with a density of 1.75-1.85 g cm^{-3}, porosity up to 20-25% and filtration coefficient up to 10-0.05 cm day^{-1};

(c) the lower zone of strongly compressed wastes with a density of 1.85-2.0 g cm^{-3}, porosity up to 10-12% and zero values of filtration coefficient.

High values of porosity and filtration coefficient in the upper part of the halite formations give favourable conditions for vertical filtration. This allows the action of erosion processes which resemble those in karst.

The intensity of karst development is strongly influenced by climatic conditions, especially the degree to which precipitation exceeds evaporation. This is the case for the potassium mills of Byelorussia and the Urals (USSR).

Salt karst is relatively rare at the surface since usually the saltbearing rocks lie at great depths, where often the formations of earlier karstic phases become deformed or destroyed (Korotkevich, 1970). For this reason studies of erosion processes taking place in surface salt deposits, such as potassium mill salt dumps, is of scientific interest.

Karst cavities in the salt dumps are the result of solution. Absolute values of sodium chloride solubility in water vary between 356.5 and 391.8 g l^{-1} in a range of temperatures 0-100°C. Studies of dissolution rates of rock salt have been performed by many scientists. Salt leaching intensity depends on flow velocity and flow volume, drainage pattern, presence of impurities, temperature, etc. The larger the surface of contact with the solvent the higher the rate of rock salt solution. Since the upper parts of salt dumps are noted for high porosity the solution rate of such salt deposits is higher than that in laboratory monoliths. As atmospheric precipitation becomes saturated by salt in solution its leaching capacity decreases - this occurs with depth in the salt dump.

Karst phenomena on the salt dumps

Field inspection of salt dumps shows relief forms on their surface related to the development of karst features at depth. Salt dumps can be regarded as analagous to Mediterranean karst (open karst). Types of karst features on the dumps include furrows, canals, honeycombs, small alveoles, cones and other depressions divided by crests (cirques and similar relief). The depth of furrows on waste heap slopes varies from several centimetres up to 0.8-1.0 m. The crests, dividing the furrows, are smooth and rounded in shape. Cirques are usually found on all salt dump slopes (Shpakov & Klementyev, 1979).

As the result of leaching by infiltrating precipitation the surface of salt dumps is covered by a crust of clay minerals (the insoluble residue of halite wastes).

In places where waste heaps overlap at their bases, V-like depressions resembling karst sinkholes are widely found. Small karst cones, 20-35 cm in diameter, are also found at the base and on the slopes of these depressions. Less frequently, karst oval wells 1.5-2.5 m in diameter can be observed. Their depth sometimes reaches 2.3 m and their formation is usually related to the collapse of karst galleries.

There are also karst cones developed on salt dumps. They are of irregular form, 0.5-1.0 m in diameter and conical in profile. Karst cones (craters) are the most common salt dump relief forms, and are often connected through horizontal or sloping galleries which may be several dozens of metres long. Along the periphery of salt dumps there are outlets of the major springs. In cross section, gallery dimensions vary from 0.3-0.4 up to 1.2-1.7 m. Chemical analysis of brine samples, taken along the salt dump peripheral springs shows that their salt concentration varies within the range of 340-360 g l^{-1}.

Halite formations are characterized by extremely active karst processes (Rodionov's coefficient of karst activity exceeds 300). This is why the study of karst hydrogeology in artificial salt deposits is of great importance from the point of view of protecting groundwater from pollution (Bogomolov *et al.*, 1974).

Quantifying the erosion rates

A balance of water and salt may be outlined for the salt dumps. Brine flow from salt dumps is the result of atmospheric precipitation and condensation of moisture; these are inputs. A certain amount is lost to evaporation (output). The constant flow of brine from the salt dumps, via the springs on their periphery indicates that precipitation and condensation exceed evaporation. The balance is described by the equation:

$$Q = (Q_{ap} + Q_c - Q_{evap})F \cdot 10^{-3} \quad (1)$$

where Q = flow discharge of brines at salt dumps (m^3 $year^{-1}$); Q_{ap} = quantity of atmospheric precipitation; Q_c = quantity of condensational moisture received from air (mm $year^{-1}$); Q_{evap} = quantity of moisture evaporating from the surface of salt dumps (mm $year^{-1}$); and F = area covered by salt dumps (m^2).

The elements of this balance can be easily determined. Spring discharges along the dump periphery can be measured so long as the wastes are stored on brine-tight screens (Shpakov & Klementyev, 1979). Knowing that brine mineralization usually amounts to 340-360 g l^{-1}, the quantity of salts carried from salt dumps, as the result of solution can be determined:

$$S = Q M_{av} \quad (2)$$

where S = total quantity of salts carried out of the salt dump (m^3 $year^{-1}$); and M_{av} = average brine mineralization (t m^{-3}).

During the studies made in the Soligorsk mining region it was found that on average 25 m^3 day^{-1} of brine is discharged; solutional erosion of salt dumps amounts to 3.6 m^3 day^{-1} from an area of 1 ha. The large volumes of halite wastes stored annually mean that the total quantity of brine formed equals hundreds of thousands of cubic metres. Though the potassium industry does not obviously produce a water waste, the dumping of readily-soluble salt wastes on the land surface in climatic zones of surplus moisture results in much brine formation.

Wind erosion of salt dumps is less pronounced. This is the result of the development of cementation between separate grains of the waste material and physico-chemical processes of lithification. The result of these processes is the transformation of the salt dumps during the first 1.5-2 months into semi-rock features. That is why the erosion of salt dumps depends greatly on their height, wind load and duration of droughts. The product of wind erosion is a fine dust (of small salt particles and, in lesser quantities, clay particles). With the help of lysimeters installed round the salt dumps, it was found that the annual wind erosion of salt particles from 1 ha of salt dump does not exceed 6 t.

Environmental damage

Water and wind erosion processes on unprotected salt dumps result in certain damaging environmental effects. Communication routeways, constructed on salt dumps for the handling of wastes become damaged. Wind erosion causes salinization of nearby agricultural lands. Surplus brine accumulation threatens to break through protective dams onto adjacent land; such accidental breaks have already occurred.

Brines penetrating into fields have transformed fertile plough-lands into lifeless solonchak (white alkali soil), anihilating vegetation for 1-2 years. During the summer dry period the soils are covered with cracks and a white powdery coating, consisting of sodium chloride salts. Total desalinization of 1.5 m thickness of soil occurred only 5 years later (Bogomolov *et al.*, 1975).

Infiltration of accumulated brines into the aquifers results in salinization of groundwaters. Aureoles of salinized groundwater occur round dumps. Salinization observed in a gley soil area occurred up to 2 m deep. There was no noticeable washing out of salts from the soil by atmospheric precipitation. The salts, sodium chloride mainly, underwent seasonally reversed migration during the year. In dry warm weather they would rise through capillaries to the surface of the soil, where they accumulated in great quantities, and in wet periods they were washed out of the upper horizons. This behaviour lasted for 9 years and only when drainage works aimed at lowering the level of groundwaters were carried out did the content of salts in the soil begin decreasing.

Salinization by brines is having a great effect on the soil's capability to adsorb and retain solutes. This property of the soil normally protects readily soluble substances such as fertilizers from leaching (saving them for the nutrition of plants). The content of cations absorbed in exchange by soil is responsible for its fertility and is of extreme importance. The availability of hydrogen ions in the adsorbed state makes the soil acid, and adsorbed ions determine its fertility (e.g. cations of Ca, Mg, K, NH_4).

Soil salinization, especially by sodic salts, changes the content and composition of exchange cations. Gedroyts (1935) pointed out that even the short-term occurrence of sodium salts in soils results in sodium appearing in the adsorbing complex.

Soil salinization by brines containing sodium chloride and potassium chloride has greatly changed the cation adsorbtion properties of soils. In podsolic as well as gley soils the content of Na, K and H increases abruptly as a result of expulsion of exchanged Ca and Mg. Ca and Mg, become very mobile in the presence of chloride and are washed out of the soil, in the form of $CaCl_2$ and $MgCl_2$.

Brines also affect soil humus, the quantity and composition of which in turn affects fertility. The characteristic feature of humus composition in salinized soils is its high mobility. Free humic acids predominate in the composition of non saline humus, while humic acids related to calcium are almost completely absent. The general content of fulvic acids increases, and the more aggresive fractions (fulvic acid I and Ia) prevail. The content of nonhydrolysed residue as well as humic acid carbon in relation to fulvic acids carbon also decreases.

REMEDIAL MEASURES

To eliminate the harmful effects of erosion processes on salt waste heaps at potassium mills, a number of protective measures are in being or planned for implementation under the guidance of the scientific council of the USSR Academy of Sciences. ("Elaboration of a scientific basis for prevention of salinization of soils and water sources by the wastes of Soligorsk potassium mills"). The basis for the programme is long term investigation in the field and in laboratories by several specialized organizations.

(a) On the basis of the data available it is possible to forecast salt migration as the result of erosion processes and the resulting changes to the environment in the regions of potassium mills.

(b) To prevent surplus brine filtration into the underlying rocks and underground waters we have used specially designed impermeable screens (polythene film).

(c) The sinking of wells for the disposal of surplus brines into deep aquifers is carried out.

(d) Protective covers of salt dump surfaces to prevent erosion have been installed.

(e) The use of salt wastes has been encouraged in other branches of industry.

(f) Permanent management of the hydrochemical state of water resources and vegetation cover is envisaged, using geophysical methods.

Thus, the following conclusions can be made:

(a) Storage of readily soluble salt wastes of potassium mills on the land surface results in undesirable erosion processes. Karst formations result and there is an accumulation of surplus saturated brines.

(b) The intensity of erosion processes depends to a great extent on climatic conditions at the potassium mills, especially on atmospheric precipitation.

(c) The aggressive effect of erosion besides destruction of salt dumps is causing chemical pollution of the environment (of soils, water resources and, to a lesser extent, of the atmosphere).

(d) The prevention of these undesirable erosion processes has required the implementation of protective schemes.

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