The physicochemical reactions that proceed during interaction between clayey minerals and acids and alkalis with the formation of heavily hydrated gel-like neogenic formations that heave clayey soils are addressed. The chemical heaving of sandy soils is examined. Methods used to restore structures deformed by heaving soils are analyzed.

The chemical heaving of clayey soils occurs when they are wetted by aqueous solutions of acids and alkalis. It is irreversible, accompanied by a partial change in the chemical—mineralogical composition of the soils, and by itself, may exceed by several times the swelling in an aqueous medium. When heaved soils are dried, their volume exceeds by many times the volumes that they had previously occupied.

The chemical heaving of soils is manifested most frequently in the beds of foundations of industrial establishments associated with the production or use of acids and alkalis. The infiltration of acids and alkalis to bed soils, which give rise to dangerous deformations of foundations and superstructures during vigorous heaving, occur because of procedural oversights or emergency situations. Serious emergencies caused by the chemical heaving of soils in the beds of deformed structures are known in Russia and abroad.

The acidification of soils and clayey rocks is also observed, however, under natural conditions. For example, it is distinctly manifested during the weathering of argillites containing pyrite. Argillites, which are slightly metamorphosed clays, are isolated from the air prior to their exposure by mine workings. When they are exposed, the oxygen in the air oxidizes the pyrite contained in the argillites to ferrous sulfate and sulfuric acid. The reaction proceeds in accordance with the scheme

$$2\text{FeS}_2 + 7\text{O}_2 + 9\text{H}_2\text{O} \rightarrow 2\text{FeSO}_4 \cdot 7\text{H}_2\text{O} + 2\text{H}_2\text{SO}_4$$

The sulfuric acid that is formed decomposes the clayey minerals that enter into the composition of the argillites, as a result of which they disintegrate vigorously and increase their volume. Such heaving is extremely undesirable, since the mine pressure of the roof increases against the bracing and is frequently the cause of its failure, and also the formation of rock bursts in mine workings. Moreover, oxidation of the pyrites is accompanied by the vigorous absorption of oxygen from the mine atmosphere and by its enrichment with carbon dioxide, which is formed during the acid-induced decomposition of carbonates contained in the rock. According to our observations, the heaving of argillites, which is caused by oxidation of pyrites, occurs very rapidly. Thus, argillites in the roof of coal seams of the Vorkutinsk Deposit failed at a depth of 0.4 m after six months of drift exploitation.

The Scientific-Research Institute of Foundations and Underground Structures has investigated the physicochemical reactions that take place during interaction between clayey minerals and acids and alkalis. The studies indicated that the minerals actively decompose in acidic and alkaline media with the formation of heavily hydrated neogenic formations of increased volume.

An alumosilicate nucleus of clayey minerals is broken down during chemical interaction between the soils and acids: this is accompanied by the emergence of an aluminum ion from the crystal lattice and the formation of depolymerized silicic acid. The latter is formed on sections of the surficial dissolution of minerals and is stationary, while the aluminum ion, which is bound with some other acid anion, is free, and may proceed into the aqueous phase of the soil [1]. The aluminum salts of the mineral acids do not react with the depolymerized silicic acid and other components that are contained in the clayey soils.
The type of acid and the concentration affect the increase in the swelling effectiveness of clayey soils. Soils wetted by sulfuric and phosphoric acids, and to a lesser degree by nitric and hydrochloric acids, heave more actively. The heaving of soils increases with increasing concentration of all acids. Additional heaving occurs during the acid wetting of carbonate clayey soils, the carbonates of which decompose in an acid medium with the liberation of carbon dioxide. Reacting with calcium cations, which go over into solution from the decomposition of carbonates, sulfuric and phosphoric acids form bulk precipitates of gypsum dihydrate and calcium phosphate. Under these conditions, nitric and hydrochloric acids form solutions of calcium nitrate and calcium chloride, which have essentially no effect on the heaving of soils.

Chemical heaving of acidified soils increases during their neutralization by an alkali; this is governed by the condensation of depolymerized silicic acids in acidic heavily hydrated gels and by the formation of aluminum hydroxide, which bonds a large amount of free water. In neutralizing alkaline soils with concentrated solutions of sulfuric and phosphoric acids, swelling of the soils may increase as a result of the formation of crystalline hydrates of sodium sulfate and sodium phosphate salts having large molecular volumes.

The ability of acidified soils to increase their volume during neutralization should be considered in searching for methods to eliminate dangerous aftereffects. In the opposite case, even greater harm may be done to structures having undergone bed acidification when the acidified soils are neutralized.

Alkalization of clayey soils also results in their heaving, but is less effective than acid-induced heaving, and takes place in a more complex manner and at a lower rate. During alkalization, the clayey minerals are dissolved with their emanation of an aluminum ion, and the formation of depolymerized silicic acids. In an alkaline medium, an aluminum ion will form sodium aluminate NaAlO₂, which interacts vigorously with the silicic acids. Condensation of aluminosilicate gels and sodium-alumosilicate complexes occurs in that case. In contrast to acid gels, alkaline gels are less hydrated and affect the alkaline heaving of clayey soils to a lesser degree.

The reaction involving the decomposition of clayey minerals (in this case, kaolinite) by alkali with the formation of a sodium-alumosilicate complex occurs in accordance with the following scheme:

\[
\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{NaOH} \rightarrow \text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot n\text{H}_2\text{O}
\]

The effectiveness of the alkalization of clayey soils is lowered appreciably in concentrated alkaline solutions. During the neutralization of alkaline soils, their volumes increase, but to a lesser degree than during the neutralization of acidified soils.

An additional increase in the volumes of alkaline soils may occur during rapidly proceeding carbonization of the free alkali. For the case in question, soda containing 10 molecules of crystalline water of hydration are formed. Here, the molecular volume of the soda exceeds that of the sodium hydroxide by a factor of 10. When gypsum is present in the soils, the formation of Glauber's salt with a high molecular volume is possible.

The physicochemical processes that take place when clayey minerals interact with acids and alkalis are like topochemical reactions, which proceed in the solid phase, when the process is localized on the "solid initial substance/solid reaction product" interface (in our case, hydration of the clay - hydrated neogenic formations). Since these reactions proceed within the bounds of the interphase surface, the rate of the process will be proportional to the magnitude of this surface at each point in time. On the whole, the process will depend not on the rate of the chemical reaction, but on the rate at which the reacting ions diffuse through the layer the product being formed [2]. The rate of chemical heaving of soils will therefore be limited, above all, by the existence of a clayey fraction (no less than 10%) in the soils and the accessibility of acids and alkalis to this fraction. It is established that heaving occurs more effectively in permeable silty - clayey soils. In dense impermeable clays, acids and alkalis are transported by means of diffusion, and, as laboratory investigations have indicated, the diffusion rate in clays in a slightly plastic state with a moisture content close to the plastic limit does not exceed 2-3 cm/day for acids, and approximately 1 cm/day for alkalis. In both cases, the diffusion rate decreases with the passage of time.

It should be pointed out that a small portion of clayey minerals is subject to acid and alkaline decomposition. The decomposition does not exceed 6% even in concentrated solutions. This amount, however, is sufficient for the synthesis of heavily hydrated neogenic formations, which can cause vigorous chemical heaving of soils.

Uplifting of the foundations of structures is manifested not only on swelling or heaving soils. Thus, Sorochan [3] cites the case of the deformation of a building constructed on slag wastes, which increased their volume appreciably as a result of active weathering. The deformation of the building occurred after it had been in service for five years.

A dangerous situation has developed in the main frame of the Krasnopresnensk Sugar Refinery in Moscow, which is caused by vigorous heaving of the sandy bed [4]. Heaving occurred as a result of prolonged wetting of the bed soils by sodium...