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Soil Heaving in Coal Mines: Causes and Mechanisms of Development

[1]**SADCHIKOV Alexander,** *Cand. of Tech. Sc., Senior Lecturer, a.sadchikov@ktu.edu.kz,*
[2]***NEMOVA Natalia,** *Cand. of Tech. Sc., Senior Researcher, nemova-nayaly@mail.ru,*
[1]**ISSINA Nazym,** *Master's Student, nazym.issina@gmail.com,*
[1]**SHULEPIN Andrey,** *Student, shulepin_an@mail.ru,*
[1]**DZITIYEV Aslambek,** *Student, dzt.asl@gmail.com,*
[1]NPJSC «Abylkas Saginov Karaganda Technical University», 56 N. Nazarbayev Avenue, Karaganda, Kazakhstan,
[2]Institute of Mining named after N.A. Chinakal, SB RAS, 54 Red Avenue, Novosibirsk, Russia,
**corresponding author.*

Abstract. *Floor heave in coal mines is a multifaceted problem caused by a combination of mineralogical, hydrogeological, and geomechanical factors. The article examines the causes of this phenomenon, detailed mechanisms (swelling of smectite clays, plastic flow, bending and buckling of the floor), the influence of mining depth and rock pressure, as well as the associated economic and production consequences. Particular attention is paid to water saturation conditions and changes in the stress state of the rock mass. Practical methods for diagnosing floor heave, engineering approaches to its prediction and control are presented. Characteristic examples of floor heave manifestations in mine workings are given, and recommendations are provided for numerical modeling, selection of support parameters, and improvement of roadway stability. The impact of floor heave on the safety of mining operations is also considered.*

Keywords: *soil heaving, swelling, smectite, plastic extrusion, lining, geomechanics.*

Introduction

Ground heave (or floor heave, or squeezing ground) is the uplifting or bulging of rock within a mine working, leading to reduced access, damage to support and equipment, and increased operating costs. In deep mining environments, the problem is exacerbated by increased rock pressure and changes in hydrogeological conditions. Practical interest in this problem stems not only from operational safety considerations but also from economic considerations: approximately 15–25% of operating costs in some mines are associated with maintaining working stability and combating deformation.

Mechanism of swelling of rocks

Soil heaving (swelling) in coal mines is a serious problem caused by a combination of geomechanical and physicochemical factors.

The main materials and research on this topic cover the causes of the phenomenon, the mechanisms of its development and control methods [1].

The causes of soil heaving can be varied [1-3].

The main factors contributing to soil heaving in mine workings are:

- Presence of expansive clay minerals: subsoil clays often contain minerals of the smectite group, in particular montmorillonite, which are highly hygroscopic and significantly increase in volume upon contact with water (hydration swelling);

- High stress in the mountain range: redistribution of vertical and especially horizontal stresses after the construction of workings leads to the extrusion of soil rocks into the working space (plastic flow);

- Waterlogging of rocks: Water penetration from aquifers or technological processes reduces the strength and modulus of deformation of mudstones and shales, making them more susceptible to heaving.

- Geological conditions: these include the thickness and strength of the underlying rock layers, the presence of cracks, faults, and the depth of the coal seam [4-5].

The main mineralogical factor contributing to swelling is the smectite group of minerals (including montmorillonite). These minerals have a layered structure and the ability to bind water molecules in the interlayer spaces, causing a significant increase in volume upon wetting and a sharp decrease in strength upon saturation. Studies of montmorillonite images demonstrate a typical folded porous structure, which explains the high hygroscopicity and increasing deformation flexibility of the rocks upon wetting.

The presence of ions (Na^{+}, Ca^{2+}, etc.) in water affects the degree of rock swelling. Changes in the chemical composition of water (due to the opening of aquifers or industrial wastewater) can intensify swelling processes.

Flooding occurs when aquifers are exposed, water seeps through cracks, or as a result of technological operations (water drainage, flushing). Water reduces the effective strength of mudstones and shales and creates conditions for hydration swelling of smectites. The transition from a dry to a saturated state can be accompanied by a sharp increase in deformation and accelerated plastic flow.

After excavation, vertical and especially horizontal stresses are redistributed within the rock mass. If the marginal rock mass and underlying rocks are insufficiently strong, the material may deform plastically and be "squeezed" into the excavation. This manifests itself as a gradual uplift of the excavation floor and lateral deformation of the support structure.

As mining depth increases, the overall geostatic pressure and the role of shear (horizontal) stresses increase. High horizontal stresses can cause bending and buckling of relatively layered and rigid horizons, leading to localized heaving and damage to the lining.

Mechanisms of soil heaving development

Hydration swelling (swelling) the primary physicochemical mechanism is water penetrating the interlayer spaces of smectite minerals – the interlayer water causes an increase in particle volume. At the macro level, this is expressed in uplifts, crack formation, and virtually irreversible changes in volume over a long period of time [3-5].

Plastic extrusion and loss of bearing capacity occurs if rock deformation exceeds permissible limits, plastic flow of the marginal rock mass occurs. This is characterized by a slow but steady extrusion of rock into the workings, pressure on the supports, and a gradual reduction in the useful cross-section.

Bending and buckling occurs. With a high horizontal stress component, relatively layered and inflexible horizons can experience cracking and bending, visually resembling wave-like heaving. This mechanism is often combined with plastic flow in more flexible layers.

Below are examples of types of swelling (Figures 1, 2).

Diagnostics and research methods

Laboratory methods include the following:

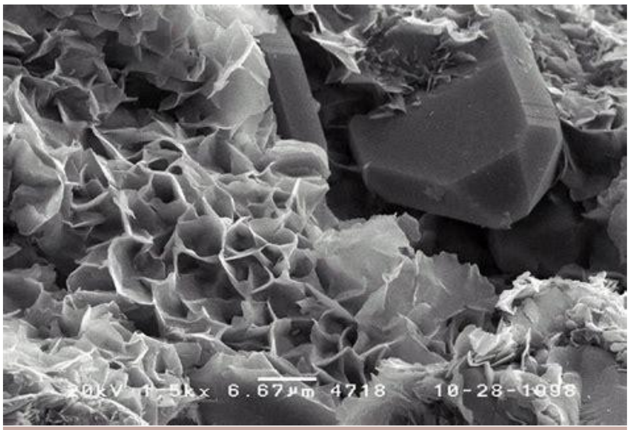

Figure 1 – SEM (scanning electron microscope) image of montmorillonite – demonstrating the microstructure of smectite minerals that leads to swelling

Mineralogical analysis to determine smectite content; petrography and SEM to study the microstructure (Figure 1); laboratory swelling tests; strength and deformation modulus tests in saturated and dry states.

Field methods are: Geophysical methods for detecting water saturation anomalies; deformation monitoring for early detection of deformation growth; hydrogeological observations and groundwater level monitoring.

Mathematical and numerical modeling: Construction of a geomechanical model of the massif (taking into account layering, fracturing, and stress distribution); numerical schemes taking into account the nonlinear behavior of clay rocks and swelling; modeling of flooding and the reaction of smectite layers.

Engineering methods for control and prevention of frost heave

Hydrogeological measures include: proper water drainage and drainage around workings; local waterproofing of hazardous areas (injections, barriers); control of water chemistry (if possible) to reduce smectite sodiumд formation [6-7].

Fastening and design solutions: and use of combined support: deformable shell, anchors and flexible elements; design of support with a reserve for possible plastic displacement (deformable support); reduction of free cross-section in the most vulnerable areas (deliberate reinforcement of areas).

Technological solutions that help reduce swelling: limiting the opening of aquifers during mining; control of process waters and chemical discharges; planning of mining to reduce stress redistribution (step mining, supported schemes) [6-7].

Research in the Karaganda coal basin using the MIKON-GEO system was conducted at the T. Kuzembaev mine of Qarmet JSC – installation traverse 46K10-V, picket 6+9.25 m (Figure 3).

Mine geophysical surveys were conducted to predict the location of accumulation areas, increased fracturing and anomalous zones, water-saturated zones and gas accumulations.

Figures 4 and 5 show the results of two- and three-dimensional water saturation inversion for the study area. Areas with increased water saturation are identified in the 30-70 m interval, indicating possible soil heaving and rock extrusion. Further tunneling confirmed the instability of the rock mass, with extensive rock folding and stratification.

Considering that up to 20% of operational losses can be associated with mine stability issues, investments in diagnostics and preventative measures typically pay for themselves through reduced downtime, support repairs, and other measures. For effective risk management, the following are recommended: early identification of areas with elevated smectite content, systematic monitoring, and implementation of response scenarios at the first signs of swelling.

For practice and further research it is recommended: Regular mineralogical monitoring of core and rock samples for the presence of smectites; implementation of a comprehensive system for real-time deformation and water level monitoring; integration of hydrogeological and geomechanical models for

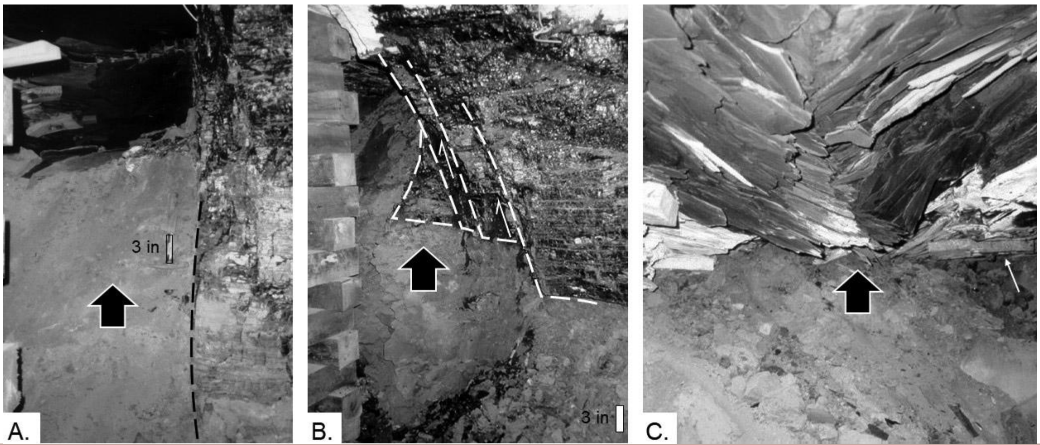

Figure 2 – Photo of soil heaving in a coal mine

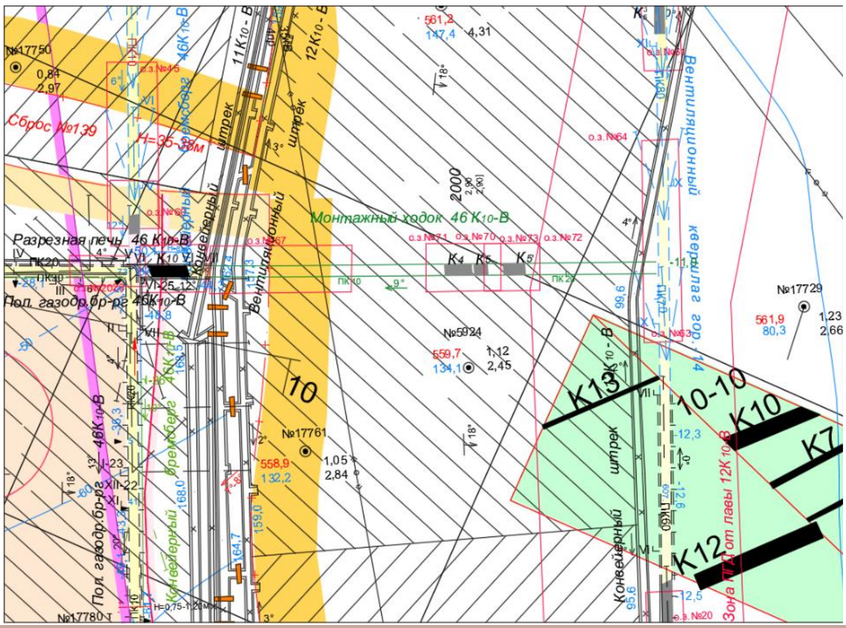

Figure 3 – Mining plan

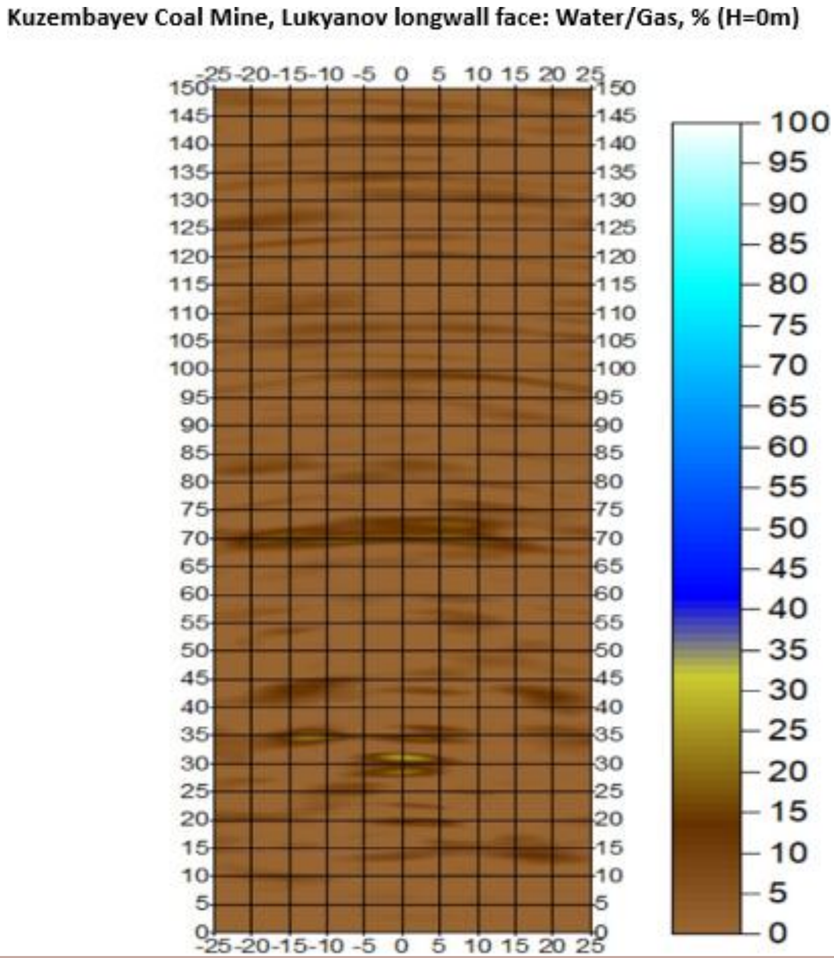

Figure 4 – Two-dimensional image of water saturation

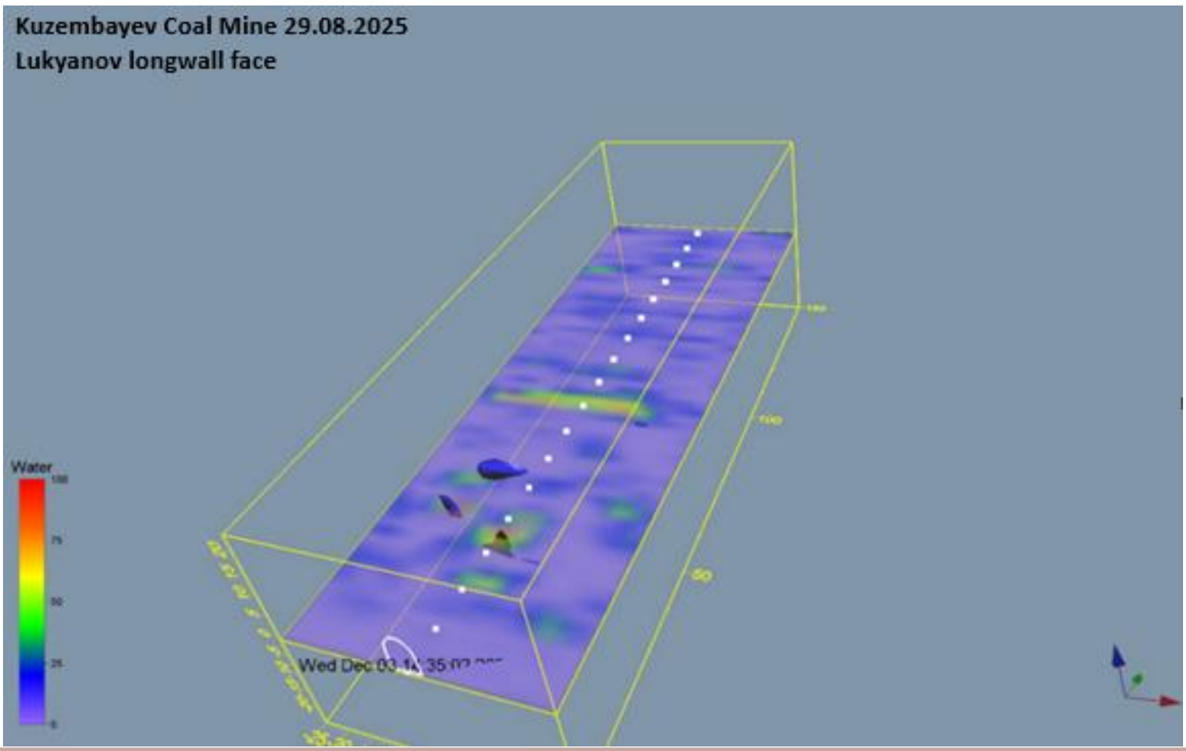

Figure 5 – Three-dimensional image of water saturation

excavation planning, taking into account the exposure of water horizons; the search for engineering solutions in the field of "support deformation"; experimental field tests to control the chemical composition of water in the working zone (to assess the possibility of reducing smectite swelling).

Soil heaving is a complex multifactorial process in which the geomechanics of clay rocks and water saturation play a key role.

Geomechanical modeling and in-situ observations are essential for predicting and managing this phenomenon.

Practical measures (support, anchoring, unloading) have proven their effectiveness, but require adaptation to specific mine conditions.

The prospect of using modern computational methods (numerical and graphical models) to improve the accuracy of forecasts and the effectiveness of engineering measures.

Conclusion

Soil heave in coal mines is the result of a complex interaction between mineralogy, hydrology, and rock mechanics. An effective heave mitigation strategy should be based on a combination of early detection (mineralogy and monitoring), adaptive support design, and hydrogeological management. For deep workings, the integration of numerical modeling with field data and the use of flexible engineering solutions capable of withstanding plastic rock flow are particularly important.

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Көмір шахталарындағы табан жыныстарының көтерілуі: себептері мен даму механизмдері

[1]**САДЧИКОВ Александр Викторович,** *т.ғ.к., аға оқытушы, a.sadchikov@ktu.edu.kz,*
[2]***НЕМОВА Наталья Анатольевна,** *т.ғ.к., аға ғылыми қызметкер, nemova-nayaly@mail.ru,*
[1]**ИСИНА Назым Ерболатовна,** *магистрант, nazym.issina@gmail.com,*
[1]**ШУЛЕПИН Андрей Николаевич,** *студент, shulepin_an@mail.ru,*
[1]**ДЗИТИЕВ Асламбек Константинович,** *студент, dzt.asl@gmail.com,*
[1]«Әбілқас Сағынов атындағы Қарағанды техникалық университеті» КеАҚ, Н. Назарбаев даңғылы, 56, Қарағанды, Қазақстан,
[2]Н.А. Чинакал атындағы тау-кен институты, РҒА СБ, Қызыл даңғылы, 54, Новосибирск, Ресей,

**автор-корреспондент.*

Аңдатпа. *Көмір шахталарындағы табанның көтерілуі минералогиялық, гидрогеологиялық және геомеханикалық факторлардың үйлесуімен байланысты көпқырлы мәселе болып табылады. Мақалада бұл құбылыстың себептері, оның егжей-тегжейлі механизмдері (смектитті саздардың ісінуі, пластикалық ағу, табанның иилуі мен қораптануы), қазу тереңдігі мен тау қысымының әсері, сондай-ақ соған байланысты экономикалық және өндірістік салдарлар қарастырылған. Су қаныгу жағдайларына және тау жыныстары массивінің кернеулі күйінің өзгеруіне ерекше назар аударылған. Табан көтерілуін диагностикалаудың практикалық әдістері, оны болжау және бақылаудың инженерлік тәсілдері келтірілген. Тау-кен қазбаларында табан көтерілуінің көрініс беруінің тән мысалдары ұсынылып, сандық модельдеу, бекітпе параметрлерін таңдау және қазбалардың тұрақтылығын арттыру бойынша ұсынымдар берілген. Сонымен қатар, табан көтерілуінің тау-кен жұмыстарын жүргізу қауіпсіздігіне әсері қарастырылады.*

Кілт сөздер: *жыныс табанының көтерілуі, ісіну, смектит, пластикалық ығысу, крепь, геомеханика.*

Пучение почвы в угольных шахтах: причины, механизмы развития

[1]**САДЧИКОВ Александр Викторович,** *к.т.н., старший преподаватель, a.sadchikov@ktu.edu.kz,*
[2]***НЕМОВА Наталья Анатольевна,** *к.т.н., старший научный сотрудник, nemova-nayaly@mail.ru,*
[1]**ИСИНА Назым Ерболатовна,** *магистрант, nazym.issina@gmail.com,*
[1]**ШУЛЕПИН Андрей Николаевич,** *студент, shulepin_an@mail.ru,*
[1]**ДЗИТИЕВ Асламбек Константинович,** *студент, dzt.asl@gmail.com,*
[1]НАО «Карагандинский технический университет имени Абылкаса Сагинова», пр. Н. Назарбаева, 56, Караганда, Казахстан,
[2]Институт горного дела им. Н.А. Чинакала СО РАН, Красный проспект, 54, Новосибирск, Россия,

**автор-корреспондент.*

Аннотация. *Пучение почвы в угольных шахтах – многоплановая проблема, вызванная сочетанием минералогических, гидрогеологических и геомеханических факторов. В статье рассматриваются причины явления, детальные механизмы (набухание смектитовых глин, пластическое течение, изгиб и коробление почвы), влияние глубины разработки и горного давления, а также связанные с этим экономические и производственные последствия. Особое внимание уделено условиям водонасыщения и изменению напряжённого состояния массива. Приведены практические методы диагностики пучения, инженерные способы его прогнозирования и контроля. Представлены характерные примеры проявления пучения в горных выработках и даны рекомендации по численному моделированию, выбору параметров крепи и повышению устойчивости выработок. Также рассматривается влияние пучения почвы на безопасность ведения горных работ.*

Ключевые слова: *пучение почвы, набухание, смектит, пластическое выдавливание, крепь, геомеханика.*

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