Natural geochemical hazard as a pseudo-component of negative environmental impact of mining complexes

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Abstract. The paper presents the authors’ research findings that enable to avoid unreasonable charges for negative environmental impact by applying mathematical statistics and GIS technology, modern methods of geochemical sample data processing, as well as by analysis of the dynamics of engineering-geological phenomena in the mining complexes areas. The authors’ data on the manifestation of high concentrations of toxic elements in some landscape components on the territory of mining complexes are provided. The latter, according to the authors, are associated with the outcrop of molybdenum ore occurrences, which were previously blocked by thin Pliocene deposits. Then, due to sloughing of these deposits, molybdenum compounds began penetrating to the environment components.

1 Introduction

The purpose of this paper is to show how to avoid unjustified charges for negative environmental impact using mathematical statistics and GIS technology, by applying modern geochemical data processing methods, as well as analyzing the dynamics of engineering-geological conditions in mining complexes areas. The relevance of the research is explained by the fact that mining and processing complexes (MPC) are usually located in the immediate vicinity of mineral extraction and enrichment places, such as quarries, mines, tunnels, processing plants, tailings and sludge storage facilities, etc. Their operation provides for installing an environmental monitoring network and maintaining within the mining allotment boundary (i.e. the so-called local or industrial (object-based) monitoring) of mining and processing complexes, as well as in the zone of their environmental impact. The environmental monitoring program normally includes mandatory routine observations of toxic elements (TE) concentration and their compounds in surface and ground water, bottom sediments, soils and other landscape components. At the same time, the TE content, as a rule, significantly exceeds the maximum allowable concentration (MAC) value in many components of the natural environment. It refers to the chemical elements that make up the ores extracted and processed at the MPCs, as well as chemicals used for ore concentrating and processing.
The Khibiny Tundra. It includes the existing Kirovsky and Rasvumchorrsky mines and processes and the basics of landscape quality and regulations. SanPiN 2.1.7.1287-03, due to natural features of the natural ore-deposit associations of the deposit formation affiliation of the deposit type and many others. Among foreign scientists, made a suggestion on the first time by S. Perelman and other domestic and foreign geochemists and was introduced by the Geochemistry of natural and mining landscapes and many others. Among foreign scientists, made a suggestion on the first time by S. Perelman and other domestic and foreign geochemists and was introduced by the Geochemistry of natural and mining landscapes and many others.

Brief description of the research object

The research is focused on studying the chemical anthropogenic impact of industrial activities. It includes the identification of polluted areas and the assessment of their impact on the environment.

For this purpose, the methodologies of SanPiN 2.1.7.1287-03 were developed and adopted to assess the chemical anthropogenic impact of industrial activities. The calculations of which are based on testing (chemical elements concentrations) of the various media of the environment, such as underground and surface waters, bottom sediments, and other landscape components. Most often, this is how geochemical anomalies manifest in depositing media and, especially, in bottom sediments.

As was shown earlier [5], the pollution caused by industrial activities in most of the studied landscape elements is observed in the Altai, Co, Sr, Mo, Sc, as well as As, Tl, Cu, Zn, Pb, Ba, Mn, B, Li, and many others. Among foreign scientists, made a suggestion on the first time by S. Perelman and other domestic and foreign geochemists and was introduced by the Geochemistry of natural and mining landscapes and many others.

The authors identified a number of geochemical provinces that are characterized by high intensity and complexity. At the same time, the normalizing bulk value of the natural geochemical component allows one to clearly distinguish between the natural geochemical component of the region and the man-made geochemical anomalies. This factor was used by the authors to identify the geochemical hazard that arises due to natural processes and the impact of man-made processes. The authors suggested the use of the Arzhanova and Kukisvumchorr deposit indicators to assess the chemical anthropogenic impact of industrial activities.

The calculation of the ith pollutant concentration of chemical ore elements, the natural background concentration of the same substance, and the normalizing value of the natural geochemical component allows one to determine the indicator of soil pollution (which is used for mineral prospecting. Later, it began to be used in ecology.

One of the approaches to assess the pollution caused by industrial activities is the calculation of the specific pollution index (also called the partial geochemical hazard index). This index is calculated as follows:

$$I_d = \frac{C_{\text{poll}}}{C_{\text{background}}}$$

where $C_{\text{poll}}$ is the concentration of the ith pollutant in the studied medium and $C_{\text{background}}$ is the natural background concentration of the same substance. The specific pollution index is a dimensionless value that indicates the level of pollution caused by industrial activities in a given medium.

The authors concluded that the specific pollution index can be used as an indicator of soil pollution and can be applied in various media of the environment, such as underground and surface waters, bottom sediments, and other landscape components. This approach allows one to assess the pollution caused by industrial activities and to identify the areas with the highest level of pollution.
of JSC Apatit (Fig. 1). These deposit fields are located on the Kola Peninsula (Murmansk Region). They are characterized by large ore reserves, a long period of their mining (more than 80 years) and a wide range of environment pollutants, including highly toxic elements \[10\].

The deposit fields are confined to the Khibiny intrusive, which is the largest alkaline massif known in the world. It is characterized by a conical structure. Along the boundary of the outer and inner syenite complex, rocks of the iylolite-urtite series are embedded, with which significant ore deposits of apatites are associated. The mineral field is represented by a single reservoir deposit. Mineral composition of apatite-nepheline ore (%)

\[
\begin{align*}
\text{apatite} &\quad (10–91.5), \\
\text{nepheline} &\quad (3.16–73.5), \\
\text{pyroxene} &\quad (3.21–17.57), \\
\text{sphene} &\quad (\text{decimal places}) \\
\end{align*}
\]

The content of the main components in the ore (%)

\[
\begin{align*}
P_2O_5 &\quad 14.48; \\
\text{SrO} &\quad 1.18; \\
\text{Al}_2O_3 &\quad 14.23; \\
\text{Ga} &\quad 0.0015; \\
\text{Rb}_2O &\quad 0.0095; \\
\text{CeO} &\quad 0.0000025; \\
\text{TiO}_2 &\quad 1.84; \\
\text{Nb}_2O_5 &\quad 0.16 [11, 12].
\end{align*}
\]

Fig. 1. Location of the research objects within the area of the Apatit mining complex \[10\].

2 Materials and methods
3 Results and discussion

Increased concentrations of Mo were recorded by the authors in underground and surface waters, bottom sediments and soils in the zone of influence of the tailings dump of the operating apatite-nepheline processing plant of JSC "Apatit" (ANOF-3, see Figure 1). This was also confirmed by the object-based (local) monitoring of the above-mentioned environments. When mapping the territory adjacent to the mining complex, ore occurrences of this element were identified. During the engineering-geological survey of the area, it was found that before the development of the Kukisvumchorr apatite-nepheline deposit, the ore occurrences of molybdenum, being hypsometrically higher, were blocked with Pleistocene deposits. Over time, their sloughing occurred (the traces of which were recorded by the authors), the bedrock was exposed and began to collapse. Due to sheet flood and other geological processes, mainly of a gravitational nature [14], molybdenum compounds penetrated into bottom sediments. When their accumulation became critical, it contributed to secondary pollution of surface waters, which is typical of the areas of MP Cs’ activity, where supercritical concentrations of ore elements often accumulate in bottom sediments [7]. As the result, molybdenum (Mo) turned out to be among the pollutant elements, for excess discharge of which the company has to pay increased charges for harmful environmental impact. Of course, it is also necessary to prove that the landslides were not caused by cutting the slopes during the construction of the apatite-nepheline tailings processing plant of the second stage (ANOF-2) and not due to seismic impact from explosions at the Kirovsky mine quarries or other man-made processes. However, there are a number of counterarguments to these assumptions, and namely: the construction of the ANOF-2 tailings dump and the transition to underground mining technique (and, consequently, a significant decrease in the seismic load on the environment) occurred long before the activation of the landslides described above. On the other hand, a gradual increase in precipitation according to the Khibiny meteorological station data is observed from year to year, and this trend (climate change towards its humidification) occurs everywhere, especially in mountainous and foothill areas [15]. As is known, the activation of landslides is greatly facilitated by waterlogging of slopes and, especially steep slopes, having clay or loam at the base. And it is mainly such rocks that represent moraine debris that overlapped, albeit with an insignificant cover, the bedrock of the slope. Thus, the landslide activation is most likely associated with natural phenomena and is not caused technogenically.

Then, in order to differentiate natural and man-made anomalies of chemical elements, the authors carried out a procedure for normalizing the concentrations of chemical elements in soil level B to those in soil level A over the entire research area. It means that at each sampling point the concentration value in soil level B was divided by the value in soil level A. Subsequently, by applying GIS technologies, Maps of distribution of the element concentrations ratios (in this case Mo) in B/A soil levels were compiled. Since, as a rule, ore elements accumulate in the soils of level B, and technogenically conditioned elements accumulate in soil level A, such a procedure makes it possible to identify natural accumulation (enrichment) of individual chemical elements in soil. The figure below shows such a map for molybdenum concentration values.
Fig. 2. Location map of molybdenum concentration ratios in B and A soil levels (Compiled by the authors)

This map shows the distribution of the molybdenum concentration ratios in the soil levels B and A and makes it possible to localize the anomaly of molybdenum of ore genesis in the immediate vicinity of the northeastern part of the tailings dump and hypsometrically above it. The later postulate (about ‘ore genesis’) is also confirmed by the fact that abnormal geochemical fields (AGF) of molybdenum satellite elements (As, Ag, Zn Cu, Sb, W and a number of rare earth elements) are localized within the same contours.

In addition, to substantiate the ore genesis of a number of AGFs in the zone of influence of the Apatit Mining and Processing Complex, which is engaged in both extraction and enrichment of apatite-nepheline raw materials, the authors performed a factor analysis (FA).

For this purpose, soil samples were taken within the area of activity of the above-mentioned MPC. Then, based on the results of mass spectrometric analysis ICP-MS, the FA by the principal component method was performed. This method is known to be the most convenient for 'compressing' data in order to identify generalized characteristics of the nature or phenomenon being studied. Its main condition is that the main components are independent, and their number is equal to the number of original features.

As the result of factor analysis, two bipolar associations of chemical elements were identified. The first one includes phosphorus and rare earth elements (Ho, Er, Dy, Tb and others) – typomorphic elements of mineral deposits. The second association (Mn, Fe, Mo, As, Cd and some others) combines elements that accumulate in soils in the MPC influence zone and is obviously related to ore processing. Moreover, the spatial distribution of the association of the first row of elements shows that they are located in the ore extraction zone, and the second association is manifested in the zone of ore transportation and enrichment, i.e. its nature is man-made.

4 Conclusion

Thus, using the authors' materials as an example, it is shown that in order to isolate the contribution of natural factors, it is possible to substantiate that the excessive charges for harmful impact of MPC on the environment are unjustified. To do this, the following actions are necessary:

1. to study archival materials and literature, as well as local monitoring data of the survey area;
2. perform geochemical sampling and engineering-geological survey of the MPC's impact area;
3. conduct laboratory tests;
4. set the values of the local geochemical background on the element-by-element basis;
5. use methods of mathematical statistics (and FA in particular,) to interpret the data obtained;

6. apply GIS technologies for geochemical data processing and for compiling the maps, which allows getting a visual spatial representation of the toxic elements distribution and their normalized values.

The set of above-mentioned actions provides for avoiding unreasonably high charges for the adverse impact on the environment (if it is caused by the manifestations of toxic elements of natural genesis) in the mining and processing areas.

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