Geological distribution, mineralization, and industrial prospects of the element gallium in the polymetallic deposits of Uzbekistan

[1]Shodiev Abbos, [2*]Abdiazizov Asliddin, [3]Bakhromov Bekhruzbek

[1]Karshi State Technical University, Doctor of Technical Sciences (DSc)

[2*]Assistant, Karshi State Technical University tel: +99895-336-43-93

ORCID ID: 0009-0001-4958-6052

[3]Student, Karshi State Technical University

Abstract: This article provides a comprehensive analysis of the occurrence patterns, geochemical properties, and industrial significance of the element gallium in the polymetallic and gold-ore deposits of Uzbekistan. The Kurgoshinkon, Khandiza, and Kokpatas ore fields were studied as the primary objects of research. The genetic association of gallium with sphalerite, chalcopyrite, and other sulfide minerals, its concentration in metasomatic zones, and its occurrence in hydrothermal solutions were scientifically investigated. Furthermore, the strategic importance of gallium in modern electronics, semiconductors, and space technologies is also highlighted. The research findings indicate that there is potential to establish a gallium resource base through the comprehensive development of Uzbekistan's polymetallic deposits.

Keywords: gallium, polymetallic deposits, Kurgoshinkon, Khondjiza deposit, Kokpatas deposit, sphalerite, chalcopyrite, rare metals, hydrothermal mineralization, metasomatism, geochemistry, metallogeny, semiconductors.

INTRODUCTION.

The development of high-tech industries in the global economy is sharply increasing the demand for strategic and rare metals. In particular, the element gallium plays a crucial role in modern microelectronics, optoelectronics, and space technologies. Gallium-based compounds such as gallium arsenide (GaAs) and gallium nitride (GaN) form the basis of high-frequency electronic devices, laser diodes, LED systems, solar panels, and radar technologies.

Although gallium is widespread in the Earth's crust, it does not form independent minerals. It primarily occurs as an isomorphic impurity in zinc, aluminum, and polymetallic ores. For this reason, gallium is often extracted as a byproduct during primary metallurgical production processes.

The territory of Uzbekistan is situated in geologically complex metallogenic zones and is considered rich in polymetallic and gold-ore deposits. Deposits within the Kurama mountain range, the Almalyk ore district, and the Kyzylkum metallogenic province are among the promising gallium-bearing sites.

The purpose of this article is to scientifically analyze the geological distribution of gallium in the polymetallic deposits of Uzbekistan, its connection to ore-forming processes, its mineralogical associations, and its industrial prospects.

LITERATURE REVIEW

The element gallium was discovered in 1875 by Paul-Emile Lecoq de Boisbaudran through spectral analysis. It was later proven that gallium was the element "eka-aluminum" previously predicted by D.I. Mendeleev.

Fundamental research on the geochemistry and metallogeny of gallium has been conducted by scientists such as V.I. Smirnov, A.A. Beus, R.W. Boyle, and Levinson. They studied the migration of gallium in hydrothermal solutions and the mechanisms of its isomorphic bonding with sulfide minerals.

The first scientific data on gallium-bearing deposits in the territory of Uzbekistan are found in the research of S.T. Badalov, I.M. Golovanov, R.A. Musin, and A.V. Korolyov. In particular, high concentrations of gallium have been identified in the zinc ores of the Kurgoshinkon and Khandiza deposits.

According to the data obtained, gallium primarily accumulates in sphalerite and passes into zinc concentrates. In some cases, it is also observed in the minerals chalcopyrite and pyrite. Traces of gallium have also been recorded in the gold-sulfide mineralization of the Kokpatas deposit.

In recent years, due to the growing importance of gallium as a strategic metal, the complex development of polymetallic deposits has become one of the most pressing scientific and practical problems.

RESEARCH METHODOLOGY

Throughout the research, a comprehensive suite of modern scientific methods was employed to determine the geological distribution of the element gallium, its role in ore-forming processes, and the principles governing its accumulation in ore-bearing zones of industrial significance. The initial stage of the study utilized the geological-stratigraphic analysis method to examine the territorial distribution of gallium-related mineralization, its position within the stratigraphic section, and its relationship with tectonic structures. This method clarified the formation period of ore-bearing layers, the stages of their geological development, and the evolutionary characteristics of the mineralization process. In particular, the genetic link between gallium and aluminum and polymetallic ores was analyzed based on stratigraphic cross-sections.

Additionally, the mineralogical-petrographic study of ores was a crucial stage of the research, in which the mineral composition, texture, and structural features of ore-bearing rocks were investigated through microscopic analysis. This process established that gallium primarily occurs isomorphically in minerals such as sphalerite, bauxite, nepheline, alunite, and other aluminosilicates, and the forms of its association with ore-forming minerals were evaluated. Petrographic observations also identified metasomatic rocks formed under the influence of hydrothermal alterations and determined their role in gallium mineralization.

Using geochemical and metallogenic interpretation methods, the migration of gallium in the Earth's crust, its concentration factors, and its distribution patterns across ore-bearing provinces were analyzed. Based on this approach, the geochemical associations of gallium with other rare and dispersed elements, including germanium, indium, and zinc, were studied. The results of metallogenic analyses determined the tectonic-magmatic conditions of ore formation and the geodynamic environment of mineralization, thereby creating the potential to forecast prospective areas for gallium.

During the study, special attention was also devoted to analyzing the composition of sulfide minerals. Based on chemical and spectral analyses performed under laboratory conditions, the gallium content in sulfide minerals such as sphalerite, galena, and pyrite was determined, and its degree of distribution in the ores was assessed. This method yielded significant scientific results in identifying the conditions for gallium accumulation at industrially significant concentrations.

Through the study of metasomatic zonation, the spatial development of hydrothermal alterations that occurred during the ore-forming process and their connection to gallium mineralization were analyzed. Based on the composition of metasomatic zones and their mineral associations, the internal zonation of the ore bodies was determined, and the most favorable geochemical conditions for gallium accumulation were characterized. This served as an important criterion for evaluating ore fields and identifying prospective areas.

Furthermore, by analyzing archival and repository materials, the results of previously conducted geological exploration work, drilling data, laboratory analyses, and historical geological reports were synthesized. This information was compared with new research findings, and existing scientific perspectives on gallium were revisited and enriched.

Using the method of comparative synthesis of scientific literature, research conducted by foreign and domestic scholars was analyzed, and modern scientific approaches to gallium mineralization were studied. As a result, scientific conclusions were formulated regarding the general principles of gallium formation in various geological conditions, its industrial importance, and innovative technologies for its extraction.

The distribution of the element gallium in ores was evaluated from the perspective of isomorphic substitution and migration with hydrothermal solutions.

DISCUSSION AND RESULTS

Gallium is a Group III element of the periodic table and is chemically similar to aluminum. Its average abundance in the Earth's crust is estimated to be around 15–19 g/t. Gallium is distinguished by the fact that it does not form its own independent minerals in nature.

Gallium is significant for the following properties:

- low melting point (29.8° C);
- high electrical conductivity;
- corrosion resistance;
- formation of semiconductor compounds.

The occurrence of gallium in nature is found in the minerals listed in Table 1.

Table 1. Types of gallium-containing minerals in Uzbekistan

Mineral	**Chemical Formula**	**State of Gallium**
Sphalerite	ZnS	Isomorphic admixture
Chalcopyrite	$CuFeS_2$	Micro-impurity
Bauxite	$Al_2O_3 \cdot nH_2O$	Adsorbed
Germanite	$Cu_{13}Fe_2Ge_2S_{16}$	Associated element
Pyrite	FeS_2	Dispersed impurity

The similarity of the gallium ion radius to that of Zn^{2+} and Fe^{3+} ions allows for its incorporation into sulfide minerals.

Gallium Mineralization in the Kurgoshinkon Deposit. The Kurgoshinkon deposit is one of the most significant polymetallic deposits in the Almalyk ore district. The deposit's ores are of skarn-hydrothermal origin and are characterized by lead-zinc mineralization.

The main minerals of the deposit are: galena, sphalerite, chalcopyrite, pyrite, tetrahedrite, and tennantite. Gallium is primarily concentrated in sphalerite. According to research, the average gallium content in sphalerite is 4 g/t. In certain sections, this concentration may be even higher.

Gallium forms compounds with the following elements: indium, germanium, cadmium, silver, selenium, and tellurium. This fact increases the deposit's significance as a source of rare metals.

Metasomatic zonation in the Kurgoshinkon deposit was formed as a result of the multi-stage activity of hydrothermal solutions. In particular, sericite-chlorite-quartz metasomatites created a favorable geochemical environment for gallium accumulation.

Distribution of Gallium in the Khondjiza Deposit. The Khondjiza deposit is one of the major polymetallic objects in Southern Uzbekistan. The deposit's ores are of volcanogenic-sedimentary origin and are rich in lead-zinc and copper sulfides.

In the Khondjiza deposit, gallium: occurs in sphalerite, chalcopyrite, and partially in pyrite.

The gallium content varies along the vertical section of the ores. An increase in gallium and germanium concentrations is observed in the upper horizons.

This is attributed to the following factors:

- differential migration of hydrothermal solutions;
- recrystallization of sulfide minerals;
- the intensity of metasomatic processes.

One of the significant aspects of the Khondjiza deposit is the co-occurrence of gallium with indium and germanium. This enables the application of complex processing technologies.

Gallium Prospects of the Kokpatas Deposit. The Kokpatas gold deposit is primarily characterized by gold-sulfide type mineralization. However, the ores also contain associated elements such as molybdenum, selenium, tantalum, and gallium.

Gallium is observed in the following geological settings: in sulfide veins, sericite-quartz metasomatites, and pyrite-chalcopyrite assemblages.

Although the gallium concentration at the Kokpatas deposit is relatively low, its large volume of ore reserves allows it to be assessed as a promising technogenic resource.

X-ray radiometric sorting technologies employed by NMMC can serve as a basis for the future integrated extraction of rare elements like gallium.

Industrial and Strategic Importance of Gallium. Gallium is considered one of the most important strategic metals of the 21st century. Global gallium consumption is primarily concentrated in the following areas:

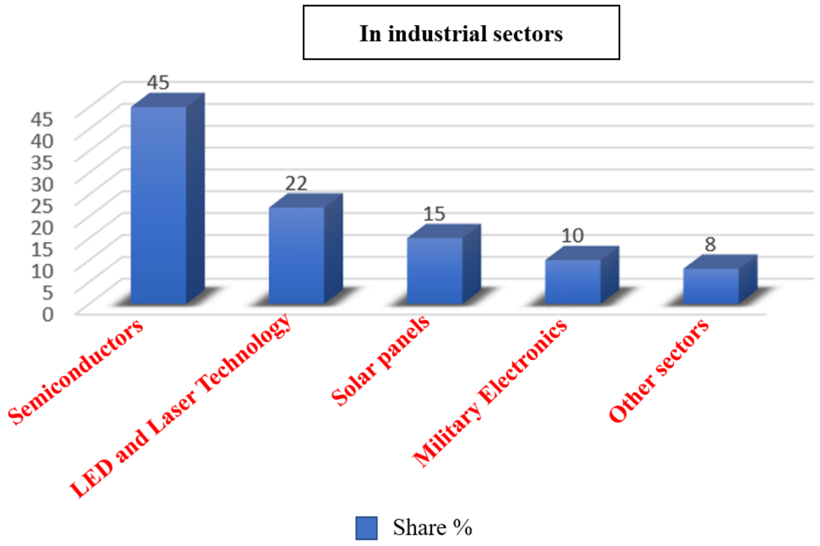

Figure 1. Diagram of global gallium (Ga) consumption by industry

Gallium arsenide (GaAs) is a semiconductor that operates at higher speeds than silicon. Gallium nitride (GaN) is distinguished by its ability to operate at high temperatures and voltages.

Gallium is widely used in the following products:

- 5G communication systems;
- radar devices;
- satellites;
- microprocessors;
- laser diodes;
- infrared optics;
- solar panels.

For this reason, countries with gallium resources are gaining a strategic advantage. China and the USA are leading in this regard.

Prospects for Gallium Extraction in Uzbekistan. Although their gallium content is low, the polymetallic deposits in Uzbekistan's territory are considered promising. In particular:

- the Almalyk ore district;
- the Kurama mountain range;
- the Kyzylkum metallogenic zone stands out as a promising region.

Gallium can be extracted from the following sources:

- zinc concentrates;
- metallurgical waste;
- waste from enrichment plants;
- technogenic deposits.

The future implementation of complex metallurgical technologies will:

- increase export potential;
- develop the high-tech industry;
- enhance the efficiency of rare metal utilization.

CONCLUSION

In conclusion, this research work establishes the following: Gallium is an important strategic associated element in the polymetallic deposits of Uzbekistan, with the Kurgoshinkon and Khondjiza deposits being among the most promising gallium-bearing sites. Gallium primarily occurs as an isomorphic impurity in sphalerite and chalcopyrite minerals. Hydrothermal and metasomatic processes play a key role in the migration and concentration of gallium. The comprehensive development of Uzbekistan's polymetallic deposits will enable the efficient extraction of rare elements such as gallium, indium, and germanium. The growing global demand for gallium further enhances the economic and strategic importance of this element. In the future, in-depth geochemical and technological research of gallium resources will be a critical factor in the development of Uzbekistan's rare metals industry.

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