Mining of Mineral Deposits
Volume 17 (2023), Issue 4, 103-108

MMD JOURNAL / MINING.IN.UA

https://doi.org/10.33271/mining17.04.103

Geological investigations and mineralogical characterization of the Awreith Gol Lead-Antimony Deposit, Chitral, Pakistan

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Abstract

Purpose. The importance of mineralogical characterization for complex ore deposits is continuously increasing due to the increasing demand for minerals worldwide. The proper mineral characterization needs to be carried out for selecting appropriate processing technology for the beneficiation of complex ore in order to efficiently obtain ore concentrate according to the market demand. The purpose of this study is to carry out a detail mineral characterization of the complex lead-antimony ore deposit of Chitral, Pakistan, necessary for selecting the most appropriate processing technology and designing a mineral processing plant.

Methods. In this research, a preliminary study was conducted on representative samples of complex lead-antimony ore deposits of the Awreith Gol area in Chitral, Pakistan to investigate and characterize the deposit prior to beneficiation, as well as to determine the processing potential of the deposit and to make a further decision on a suitable beneficiation technology. In this regard, thin section of complex ore representative samples was studied using a Scanning Electron Microscope for ore morphology analysis, EDX for chemical composition analysis, and X-ray fluorescence spectrometer analysis.

Findings. The ore deposit of the studied area is mainly composed of sedimentary rocks and intrusions of igneous rocks with varying degrees of metamorphism. Geologically, the area is characterized by the Paleozoic-Mesozoic sequence of North Karakorum system and volcano-sedimentary series. The study of mineral characteristics confirms that galena and stibnite are ore minerals containing lead 48.01% and antimony 15.43%.

Originality. The geological characteristics of the studied area have been explored. The studied ore consists of lead, antimony, stibnite and galena. The mineral characterization results have revealed that these metals can be extracted economically by selecting an appropriate mineral processing technology.

Practical implications. Mineralogical study of the mineral, combined with the chemical analysis of the ore, confirms that the lead-antimony complex ore of Chitral deposit can be beneficiated using relatively cheap gravity separation technology.

Keywords: *mineralogical characterization, beneficiation, complex lead-antimony deposit, gravity separation*

1. Introduction

Mineral-based industries play a vital role in the economic development of a country or a region by providing employment opportunity for millions of people. Furthermore, mineral-based industries also play an important role and make a significant contribution both at the local and global levels. The secret of the strong economic sustainability of technologically advanced countries is the contribution of mineral-based industry, which is considered an active partner in the economic development of the nation [1], [2]. The total world mineral consumption is about 32 billion tons per year, estimated at about $ 1213 billion per year [3], [4].

A mineral deposit is naturally occurring geologic material from which, through processing and beneficiation, a commodity can be mined profitably, thereby qualifying it as a reserve. Minerals are categorized into different groups on the basis of their chemistry, such as oxide minerals (Quartz, Silica), sulfide minerals (Galena, Stibnite), sulphate minerals (Gypsum), carbonate minerals (Limestone) and native minerals existing in elemental form (Gold) [5]. Minerals exist in the earth's crust in highly scattered and irregular manner. Extraction of a mineral from the earth's crust depends on the concentration of minerals at that point and market value [6], [7]. Beneficiation of minerals is generally influenced by geology, as each mineral has specific geologic features and mineral associations which lead to uneven distribution of mineral deposits. It is worth mentioning that the geology of minerals is different in different places, therefore a single mineral technique for processing deposits of the same nomenclature cannot be used anywhere. Similarly, the market value of a mineral deposit also affects the economics of mineral deposits. Most mineral processing waste products are now economically viable due to an increase in their market value. A mineral deposit, in terms of continuity of mineralization and market value, can be classified as either a resource that may become profitable in the future, or a reserve that has a high degree of geological certainty and is extractible technically and economically [8], [9].

Geologically, Chitral is one of the mineral-rich zones, especially in metallic minerals including lead, antimony, cop-

Received: 30 June 2023. Accepted: 19 November 2023. Available online: 30 December 2023

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Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
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per, silver, gold and rare earth elements [10]. Elements such as lead and antimony are included in the critical element category due to continuous raising market demand and low production levels. Scientists are now trying to fulfill the demand for lead and antimony through secondary recovery [11]. Lack of technical studies from an economic and environmental aspects, in-depth characterization studies to determine mineralogy, grain size for optimum mesh of grind, textural properties and locking proportions of different minerals with ore matrix, as well as unavailability of suitable flow sheet for complex lead-antimony deposit processing are the missing research gaps [12], [13].

Herein, the authors focused on performing characterization of complex lead-antimony ore deposit of Awreith Gol. Characterization techniques include a thin section study. Electron backscatter microscopy, energy dispersive X-ray analysis, X-ray fluorescence analysis and elemental mapping analysis were carried out, which confirmed that the mineralogical composition of the deposit consists of galena and stibnite, respectively. Mineralogical study combined with chemical analysis confirmed that the ore deposit can be beneficiated using relatively cheap mineral processing techniques such as gravity separations.

1.1. Geological setting of the Awreith Gol area

Awreith Gol is located (350 58′ N 710 44′ E) 4.8 kilometers southeast of Shoghore, at an altitude of 2829 m. Numerous occurrences of lead, antimony and other metals of economic significance have been found in the Awreith Gol area and nearby surroundings. Good quality lead ore is interspersed and occurs in vesicular veins, lenses, pods, stringers and forms veinlet over a radius of 620 m [12], [13]. The northern contact of the Cretaceous Shoghor limestone belt with the quartzite-schist complex of the Awreith Gol series extends up to Lutkho valley and covers an area of 30 sq km. Both series are separated by a major fault zone that displaces both units, and main studied ore mineralization is also controlled by the main fault [14], [15]. Foliation and local folding up to tens of meters in size are common in the Awreith Gol series. The Awreith limestone is more pyritized and recrystalized than the rest of surveyed zone, showing the genetic relationships between sulfosalt mineralization and dolomite pyritization [16]. Between dolomite and Shoghor limestone, discontinuity of stringers of iron-strained, orange-brown soft material with relics of quartz, pyrite, and calcite occurs [17]. The good quality of lead-antimony ore, especially its high lead content, justified the planning of extensive underground exploration. A vein of boulangerite with sufficient thickness was found right at the contact between the hanging Shoghor limestones in the southeast and highly sheared thin dolomite, interspersed with tectonic splinters of Shoghor limestone at the footwall in the northwest direction [16].

1.2. The Awreith Gol mineralization

The Awreith Gol mineralization is controlled by the main fault between the Shoghore limestone and the Awreith Gol series. The Awreith Gol series sulfosalt mineralization extends up to 12 km along the fault zone. The so-called Awreith Gol fault, mentioned on the map, is inaccessible due to rough topography. Therefore, the possible occurrence of minor complex lead-antimony deposit cannot be excluded with certainty. In the Awreith Gol series locality, dolomite is more pyritized and recrystallized, indicating genetic relationships between sulfosalt mineralization and dolomite pyritization. The host rock consists of soft, reddish-brown limonite matrix, pyrite, quartz, dolomite and black loamy clay, as shown in Figure 1 [18], [19].

2. Materials and methods

2.1. Sample preparation

Representative lead-antimony (Pb-Sb) ore deposit samples with an overall mass of 100 kg were collected from different potential spots (surface outcrops) of the Awreith Gol area of Chitral, covering an area of approximately 2.5 km^2. Out these 100, 20 kg were used for characterization and the rest were retained. Mining was carried out in most locations. Large ore lumps (> 5 cm) were crushed manually using a hand hammer to make it suitable for feeding into laboratory jaw crusher. The average feed size into a jaw crusher (JXSC PEF 150×125) ranges from 5-10 cm, which gives a product size of 1.2 cm. The jaw crusher product was passed through a laboratory roll crusher (JXSC 200×150) to obtain a product size of 2.5 mm. To obtain the bulk ore representative sample, the crushed sample was coned and quartered. To determine the mineralogical, morphological, petrological, chemical composition and textural ore features, as well as to select the most suitable processing technique for the ore deposit beneficiation, characteristic studies (thin section study, secondary electron microscopy, backscatter electron microscopy, energy dispersive X-ray analysis, X-ray fluorescence analysis and elemental mapping analysis) of a representative sample were carried out at the National Centre of Excellence in Geology, Mineral Testing Laboratory, Mineral Development Department, Peshawar and Centralized Resource Laboratory, University of Peshawar, Pakistan. Based on detailed mineralogical studies and chemical analysis, it was concluded that the ore deposit can be beneficiated using gravity separation techniques such as shaking table. The methodology adopted in this research is schematized in Figure 2.

2.2. Thin section analysis

Thin section study of the complex lead-antimony deposit was carried out in order to determine the mineralogical composition and textural feathers of the mineral and distribution of mineral grains within the ore matrix. For this purpose, four numbers of thin sections of ore samples were prepared in the Thin Section Laboratory, National Center of Excellence in Geology, University of Peshawar, Pakistan. Thin sections were examined under a polarizing microscope, focusing the microscope on different points of the section using a camera attached to the polarizing microscope assembly. Thus, color photographs of the examined spots on the section were taken.

2.3. Scanning electron microscopy (SEM)

Scanning Electron Microscopy is one of the powerful techniques used to characterize the sample surface, sample morphology and determine its chemical composition [20], [21]. To examine the ore sample under an electron microscope, thin sections were prepared from the sample and examined using a Scanning Electron Microscope, SEM Model JSM-IT-100.

2.4. Energy dispersive (EDX) analysis

EDX analysis is sometimes referred to as EDS or EDAX analysis. This is the technique used for identifying the elemental composition of the specimen or an area of interest [22].

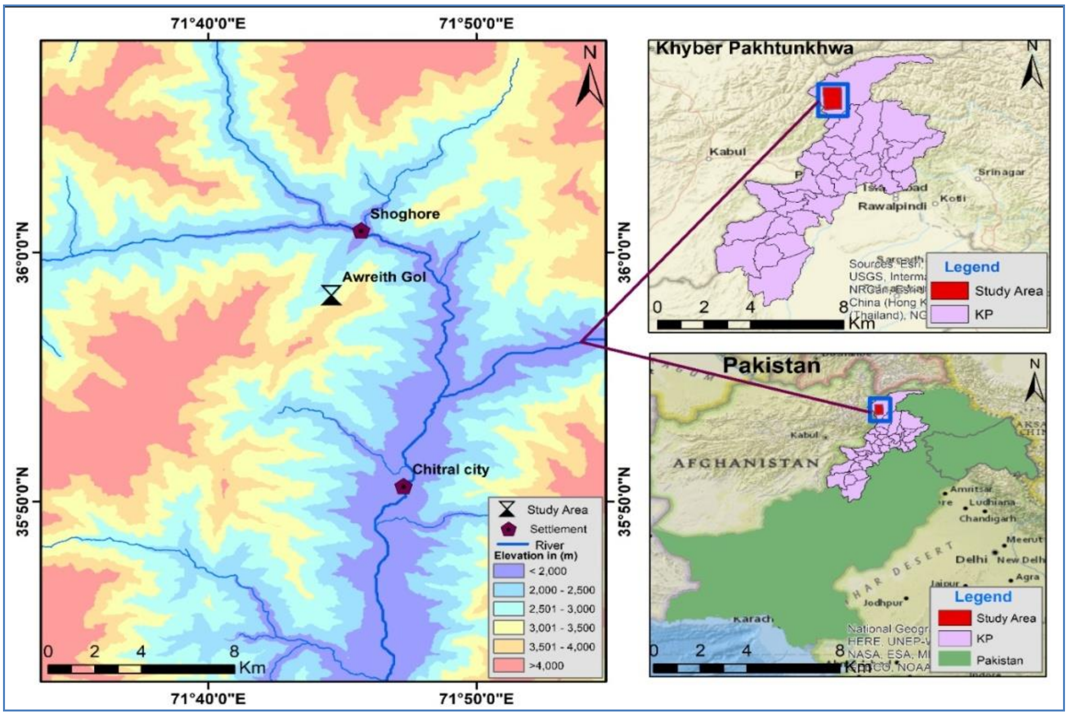

Figure 1. Location of the study area (Awreith Gol), Lower Chitral, Pakistan

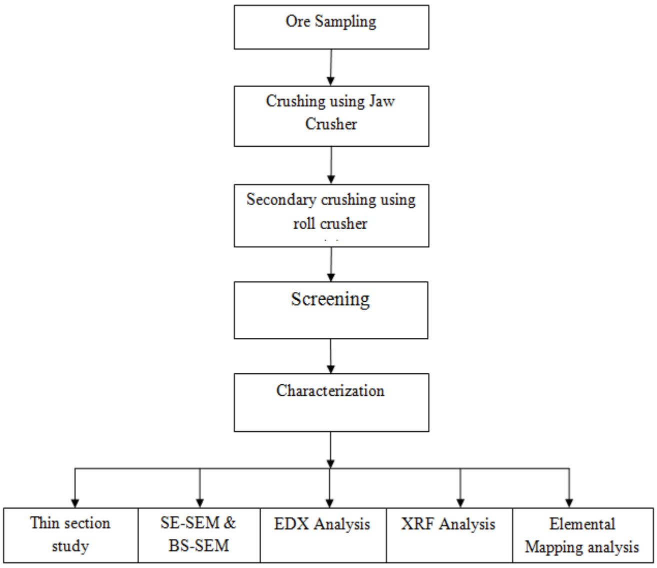

Figure 2. Research methodology adopted for characterization of complex lead-antimony ore deposit of Awreith Gol, Chitral

To determine the chemical composition with the percentage of each element in both the elemental and oxide ore deposit forms, EDX analysis of samples was carried out in the Electron Probe Analysis Laboratory.

2.5. X-rays florescence (XRF) analysis

X-rays fluorescence spectrometer is an X-ray instrument used for relatively routine and non-destructive analysis of minerals, sediments and fluids. The comparatively low cost of sample preparation, stability and ease of use of spectrometer make it one of the widely used techniques for the analysis of major and minor elements in rocks, minerals and sediments [23]-[25]. The ground ore sample was placed in front of a tube emitting high-energy X-rays. These high-energy X-rays collide with the ore sample and result in the emission of secondary X-rays, which are characteristic X-rays of the elemental composition of the sample. The emitted X-rays were detected by the spectrometer and seen on the screen attached to the spectrometer.

2.6. Elemental mapping analysis

High-resolution images obtained by Scanning Electron Microscope (SEM) and elemental spectral data using Energy Dispersive Spectroscopy (EDX) can be combined to provide extremely detailed analysis of the ore deposit and multi-phase samples [26], [27]. Elemental mapping analysis of the Awreith Gol complex lead-antimony ore deposit was performed using an SEM (JSM-IT-100) equipped with Elemental mapping imaging software. Information on the elemental composition of the single-pixel area of the digital image was obtained and indexed in an extremely short time. A computer analysis of indexed data adds color to the SEM image to correlate elements or discrete phases with individual colors. Elemental mapping analysis gave color image of the elements in the ore sample and information on grain size, grain distributions and intergrowths, textural relationships and locking characteristics in conjunction with the elemental composition within complex lead-antimony ore deposit of the Awreith Gol area, Chitral, Pakistan.

3. Results and discussion

Comprehensive data on the mineralogical composition, proportion of each element in the ore, chemical composition of the ore deposit, grain size and shape, as well as the morphological characteristics of the complex lead-antimony ore deposit of Awreith Gol were obtained using the characterization techniques. This investigation not only helped to determine associated ore minerals, but also played a significant role in the process mineralogy of the deposit. The following characteristic techniques were used.

3.1. Thin sections study

Microscopic examination of thin sections shows that the ore sample consists of coarse and elongated grains of galena and stibnite minerals with gangue minerals of pyrite and quartz. It also helped determine the size of mineral grains, the way they are arranged in the sample matrix, grain morphology and interlocking among grains. Thin section study also confirms that the grains in the sample matrix are arranged in a highly irregular manner and elongated in shape. Quartz matrix is intruded in the galena mineral, and the mineral grains are surrounded by feldspar gangue minerals, as shown in Figure 3. The average grain sizes of galena and stibnite are 1400 and 1600 μm, respectively (there is an explanation of the results, not just descriptions).

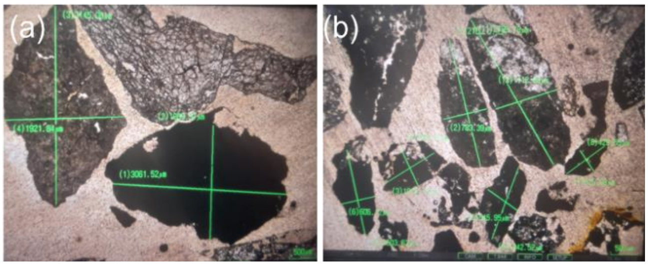

Figure 3. Thin section analysis of the complex lead antimony ore deposits of Chitral

3.2. Scanning electron microscopy (SEM)

The result can be seen on the screen attached to the SEM assembly in the form of a micrograph. Micrographs of an ore sample obtained using an SEM machine at different magnifications show that morphologically the ore deposit surface is highly rough and irregular. The mineral grains are elongated and interconnected, which looks like elongated and interconnected crystals (Fig. 4).

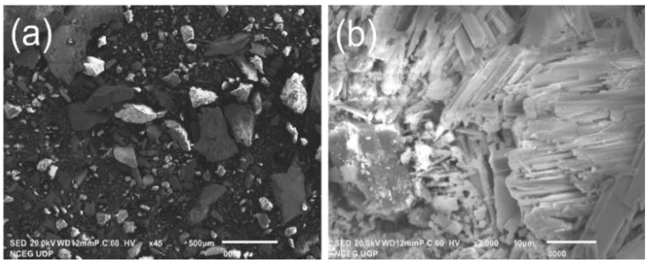

Figure 4. Results obtained from SEM: (a) micrograph obtained at power 20 kv, magnification ×45 and scale 500 mm; (b) micrograph obtained at power 20 kv, magnification ×2000 and scale 10 mm

3.3. Energy dispersive analysis (EDX)

Elemental composition of the ore sample was determined using EDX analysis and confirmed that the ore sample consists of 54.25% lead, 14.77% antimony, 8.14% iron, 5.87% sulfur, 10.43% silicon with traces of other metallic minerals. There are also rare earth elements such as actinium and copper traces of 0.14%. The EDX analysis results are shown in Table 1. EDX analysis gives the result in the form of bar graph. Therefore, both quantitative and qualitative information about the mineral samples can be obtained, as shown in Figure 5 [23].

EDX also gave the result in form of an EDX spectrum, which is a plot of how frequently X-ray is received for each energy level. The spectrum displayed peaks unique to an atom and corresponding to a single element. The peak height in the spectrum shows the element concentration, as shown in Figure 5. An EDX spectrum identifies not only the element corresponding to each of its peaks, but also the X-ray type to which it corresponds. Hence, the EDX spectrum gave both quantitative and qualitative information about the sample.

Table 1. EDX and XRF analysis results

Element	EDX **r**esults**,** %	XRF **r**esults**,** %
Lead	54.25	48.02
Antimony	14.77	15.43
Iron	8.14	3.55
Sulfur	5.87	8.69
Silicon	10.43	2.00
Magnesium	0.48	0.58
Aluminum	0.62	0.50
Oxygen	14.81	15.97
Carbon	4.74	5.48
Arsenic	1.62	–
Actinium	0.26	0.29
Copper	0.14	0.12

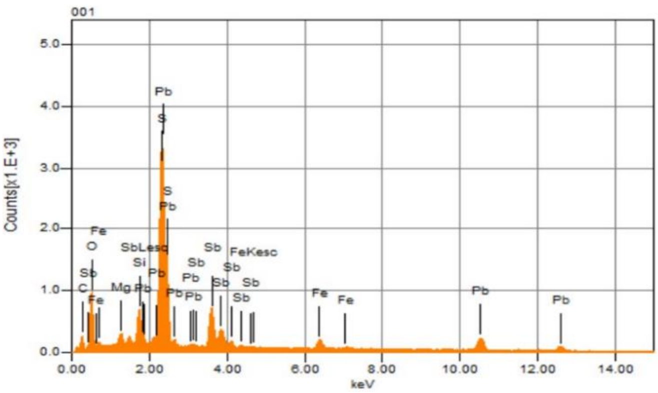

Figure 5. EDX spectrum of the complex lead-antimony ore deposit of the Awreith Gol area, Chitral

3.4. XRF analysis

The results obtained from the EDX analysis were verified using X-ray fluorescence analysis, which gave result in the form of bar graph, as well as percentage of each element within the ore sample. Results obtained from the XRF analysis confirmed that the ore sample consists of 48.02% lead, 15.43% antimony, 3.55% iron, 8.69% sulfur, 0.29% actinium, 0.12% copper and traces of other elements, such as magnesium, arsenic and aluminum, as shown in Table 1.

These results are also shown in the form of bar graph of the diffe-rent peaks. Each peak represents unique element and height of the peaks represents concentration of element. Hence, both quantitative and qualitative information about the ore sample was obtained using XRF analysis, as shown in Figure 6.

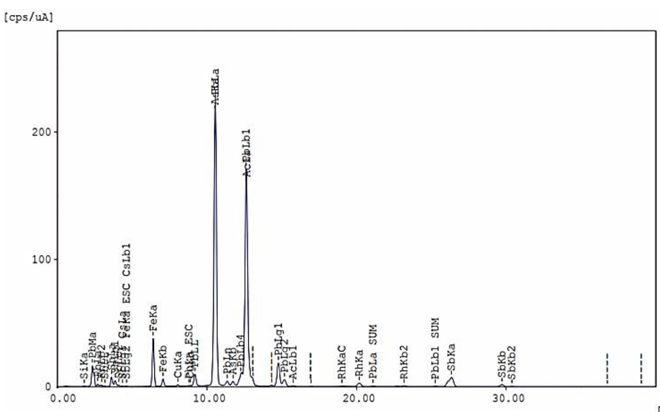

Figure 6. X-rays fluorescence analysis of the complex lead-antimony ore deposit of Chitral

3.5. Elemental mapping analysis

Close examination of the color spots confirms that lead and sulfur are associated with each other, which proves that lead and antimony exist in the ore sample in the form of sulfide. Also, the existence of sulfur in the ore sample in a highly scattered form shows that the ore minerals exist in the ore sample in the form of sulfide. Traces of other metallic and nonmetallic elements such as calcium, iron, magnesium and silicon also exist in the ore sample, represented by different colors, as shown in Figure 7.

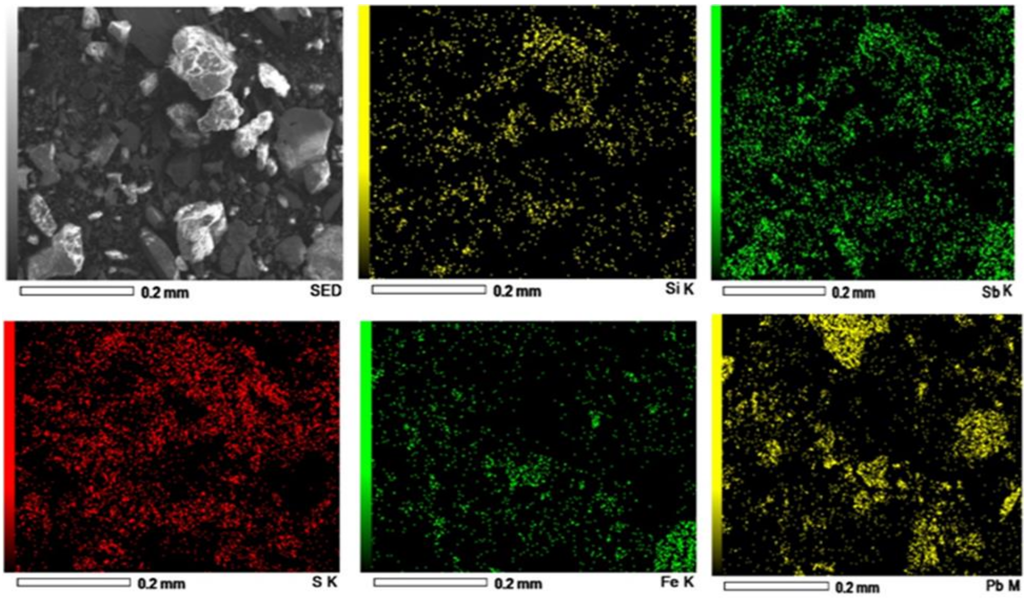

Figure 7. Elemental mapping analysis of the complex lead-antimony ore deposit of Chitral

A detailed mineralogical, morphological, textural and lithological study of the complex lead-antimony ore deposit of Chitral was conducted using some modern characterization techniques. A thin section study using a polarizing microscope confirms that the ore consists of galena, stibnite with traces of pyrite, surrounded by gangue minerals of quartzite and feldspar. The mineral grains had interconnected interlocked and elongated shape. The average grains size of ore minerals is 1700 μm. Micrographs obtained from scanning electron microscopy (BS-SEM) helped in determining the morphological information of the studied ore deposit. The micrograph taken at high magnification ×2000 shows that the ore sample surface was highly irregular and rough, as shown in Figure 4. EDX analysis helped determine the chemical composition of the sample and gave quantitative and qualitative information about the ore sample. To further confirm the chemical composition of the ore sample, XRF analysis was carried out. The EDX analysis and XRF analysis results are shown in Table 1.

Detailed information on in-depth study of the ore sample elemental composition, distribution of mineral grains and mineral grain size in the ore matrix was obtained using elemental mapping analysis. Elemental mapping analysis shows that ore sample consists of lead, antimony, iron, sulfur and silicon, and the elements in the sample matrix exist in a highly scattered manner. The distribution of elements in the sample matrix shows the complex nature of the ore deposit.

The commonly used minerals processing techniques for the processing lead and antimony ore deposits are pyrometallurgy and froth flotation. However, mineralogical and chemical investigations of the ore deposit confirmed the presence of the element arsenic, which reduces the flotation process efficiency and also causes severe environmental problems.

Mineralogical, textural and morphological features of the ore deposit were investigated. However, further investigation is required to determine the atomic structure, arrangement in the ore matrix, and bonds between minerals in the ore. The ore deposit can also be investigated for rare earth elements.

4. Conclusions

Mineralogical investigation of a complex metallic ore deposit is a challenging task and must be consider before processing the ore deposit. Characterization such as thin section study, scanning electron microscopy, energy dispersive X-ray analysis, X-ray diffraction analysis, and elemental mapping analysis have been recognized as powerful tools for in-depth study of the complex minerals. Mineralogical, textural and morphological features of the ore deposit confirmed the complex nature of the ore deposit. Thus, grinding operation is recommended to release the associated minerals. The ore was characterized as lenticular elongated texture of sand grains intergrown between each other.

Based on mineralogical and chemical investigation, as well as physical properties of galena and stibnite, it was concluded that the complex ore deposit of Chitral can be economically beneficiated using relatively simple mineral processing methods such as gravity separation methods. Also, for these elements it is necessary to investigate the existence of elements of actinium and caesium which are of strategic importance and belong to the group of critical elements.

Acknowledgements

I am grateful to Professor Dr. Ishaq Ahmad and Professor Dr. Nehar Ullah for their continuous guidance and technical support when conducting this research work. I also express my gratitude to the technical staff of Mineral Testing Laboratory, Mineral Development Department and Electron Probe Analysis Laboratory at National Center of Excellence in Geology (NCE), University of Peshawar, Khyber Pakhtunkhwa for providing technical support in conducting characteristic study of the complex ore deposit.

References

[1] Ravi, R., & Causa, H. (2018). Strategies for rehabilitation of mine waste/leachate in Thailand. *Bio-Geo-Technologies for Mine Site Rehabilitation*, 617-643. https://doi.org/10.1016/B978-0-12-812986-9.00001-4

[2] Mandal, B.B., & Hussain, S.A. (2021). *Innovative exploration methods for minerals, oil, gas, and groundwater for sustainable development*. Amsterdam, The Netherlands: Elsevier, 542 p.

[3] Wellmer, F.W., & Kosinowski, M. (2003). Sustainable development and the use of nonrenewable resources. *Geotimes*, *48*(12), 14-17.

[4] Wellmer, F.W., & Becker-Platen, J.D. (2001). World natural resources policy (with focus on mineral resources). *Natural Resources of the World*, 183-207.

[5] Wills, B.A. (2006). *Mineral processing technology*. Oxford, United Kingdom: Pergamon Press, 450 p.

[6] Radetzki, M. (2017). *A handbook of primary commodities in the global economy*. New York, United States: Cambridge University Press, 233 p. https://doi.org/10.1017/CBO9780511493584

[7] Kot-Niewiadomska, A., & Galos, K. (2019). Mineral resources in sustainable land-use planning. *Mineral and Energy Economy Research Institute of the Polish Academy of Science*, (1), 1-30.

[8] Henley, S. (2004). The Russian reserves and resources reporting system. *Discussion and Comparison with International Standards*, 13 p.

[9] Weatherstone, N. (2008). International standards for reporting of mineral reserves and resources status. *World Mining Congress & Expo*, 1-10.

[10] Malkani, M.S., Alyani, M.I., Khosa, M.H., Muhammad, I., Khalid, K., Somro, N., Tehseen, Z.T., Jawad, A.J., & Zahid, M.A. (2017). Mineral deposits of Khyber Pakhtunkhwa and FATA (Pakistan). *Research Article of the Lasbela University of Science and Technology*, (6), 23-46.

[11] Anderson, C.G. (2012). The metallurgy of antimony. *Geochemistry*, *72*(4), 3-8. https://doi.org/10.1016/j.chemer.2012.04.001

[12] Stefan, H. (2004). *Kinematics of the Karakoram-Kohistan suture zone, Chitral, Pakistan*. Doctoral Thesis. Zurich, Switzerland: Swiss Federal Institute of Technology Zurich.

[13] Shah, M.T., & Jan, M.Q. (2002). Mineral resource potential of the Himalaya, Karakoram and Hindu Kush mountains, Northern Pakistan. *Man Mountain and Medicine, Pakistan Heart Foundation*, (2), 1-30.

[14] Khan, A., & Ashraf, M. (2007). *Geological and mining resources of Chitral district NWFP Pakistan*. Quetta, Pakistan: Geological Survey of Pakistan, 126 p.

[15] Aslam, M., Khan, A., & Ashraf, M. (2007). Geology and mineral resources of Chitral district, NWFP, Pakistan. Quetta, Pakistan: *Records, Geological Survey of Pakistan*, 126 p.

[16] Sarwar, K., & Rahman, M. (2016). Economic impact of mineral resources: A case study of District Chitral, Pakistan. *Journal of Resources Development and Management*, (17), 1-15.

[17] Anjum, M.N., Arif, M., & Ali, L. (2018). Mineralogical and beneficiation studies of the Fe-Cu ores of Dammal Nisar, Chitral, NW Himalayas Pakistan. *Journal of Himalayan Earth Sciences*, *51*(2A), 108-119.

[18] Pudsey, C.J., Coward, M.P., Luff, I.W., Shackleton, R.M., Windley, B.F., & Jan, M.Q. (1985). Collision zone between the Kohistan arc and the Asian plate in NW Pakistan. *Transactions of the Royal Society of Edinburgh*, *76*(4), 463-480. https://doi.org/10.1017/S026359330001066X

[19] Shah, M.I. (2009). Stratigraphy of Pakistan. *GPS Memoir*, (22), 1-35.

[20] Erdemoglu, M., & Balaz, P. (2011). An overview of surface analysis techniques for characterization of mechanically activated minerals. *Mineral Processing and Extractive Metallurgy*, (33), 65-88. https://doi.org/10.1080/08827508.2010.542582

[21] Liu, J. (2005). High resolution scanning electron microscopy. *Handbook of Microscopy for Nanotechnology*, 325-359. https://doi.org/10.1007/1-4020-8006-9_11

[22] Klauber, C., & Smart, R.C. (2003). *Solid surfaces, their structure, and composition, surface analysis methods in materials science*. Berlin, Germany: Springer, 585 p.

[23] Cook, N.J. (2000). Mineral characterization of industrial minerals deposits at the geological survey of Norway, a short introduction. *Norgesgeologiske Under Sokelse Bulletin*, (436), 189-192.

[24] Panalytical, B.V. (2010). What is XRF. *Theory of X-rays Fluorescence XRF*, (3), 12-16.

[25] Shackley, M.S. (2011). *X-Ray fluorescence spectrometry (XRF) in geoarchaeology*. New York, United States: Springer, 231 p. https://doi.org/10.1007/978-1-4419-6886-9

[26] Kothleitner, G., Neish, M.J., Lugg, N.R., Findlay, S.D., Grogger, W., Hofer, F., & Allen, L.J. (2014). Quantitative elemental mapping at atomic resolution using Xay-Spectroscopy. *Physical Review Letters*, (112), 085501. https://doi.org/10.1103/PhysRevLett.112.085501

[27] Cabri, L.J., & Vaughan, D.J. (1998). *Modern approaches to ore and environmental mineralogy*. Mineralogical Association of Canada.

Геологічні дослідження та мінералогічна характеристика свинцево-сурм'яного родовища Аурейт-Гол, Читрал, Пакистан

У. Гані, І. Ахмад

Мета. Детальний мінералогічний аналіз комплексних свинцево-сурм'яних руд родовища Читрал, Пакистан, що є необхідним для вибору найбільш відповідної технології переробки та проєктування заводу з переробки корисних копалин.

Методика. Проведено попереднє вивчення репрезентативних зразків з родовища комплексних свинцево-сурм'яних руд в районі Аурейт-Гол в Читралі, щоб дослідити та охарактеризувати родовище до збагачення, а також визначити потенціал переробки родовища і зробити подальше рішення щодо відповідної технології збагачення. Тонкий шліф репрезентативних зразків комплексної руди досліджували за допомогою скануючого електронного мікроскопа для аналізу морфології руди, проводили рентгеноспектральний електронно-зондовий аналіз хімічного складу та аналіз рентгенівської флуоресцентної спектрометрії.

Результати. Визначено, що рудне родовище досліджуваного району складено переважно осадовими породами та інтрузіями магматичних порід різного ступеня метаморфізму. Встановлено, що у геологічному відношенні район характеризується палеозойсько-мезозойською товщею Північно-Каракорумської системи та вулканогенно-осадовою товщею. Дослідження характеристик корисних копалин підтверджує, що галеніт і стибніт є рудними мінералами, які містять 48.01% свинцю та 15.43% сурми. Результати аналізу корисних копалин виявили, що ці метали можна економічно видобувати, вибравши відповідну технологію переробки корисних копалин.

Наукова новизна. Вивчено геологічну характеристику нового досліджуваного родовища свинцево-сурм'яних руд, що складаються зі свинцю, сурми, стибніту та галеніту.

Практична значимість. Мінералогічне вивчення корисної копалини у поєднанні з хімічним аналізом руди підтверджують можливість збагачення свинцево-сурм'яних комплексних руд родовища Читрал із використанням відносно дешевої технології гравітаційної сепарації.

Ключові слова: *мінералогічна характеристика, збагачення, комплексне свинцево-сурм'яне родовище, гравітаційна сепарація*