metals

MDPI

Editorial

Jarosites: Structure, Formation, Leaching, Environmental, and Applications

Montserrat Cruells † and Antoni Roca *,†

Department of Materials Science and Physical Chemistry, Universitat de Barcelona, 08028 Barcelona, Spain; mcruells@ub.edu

* Correspondence: roca@ub.edu

† Montserrat Cruells is Honorific professor and Antoni Roca is Retired professor at the Universitat de Barcelona.

1. Introduction

Jarosite, beudantite, and alunite are members of the alunite supergroup [1,2]. The number of studies on jarosite-type compounds is incredibly extensive, and their importance appears in the fact that there are a high number of publications spanning several decades, with a high number particularly in recent years [3].

Jarosite compounds are formed through the weathering of sulfide ore, with them being generated during processes in acidic environments and acid-sulfate soils. These compounds resulting from the oxidation of mineral sulfide are also related to the recovery of the gold and silver associated with them [4]. Jarosites can be synthesized in a laboratory or precipitated in hydrometallurgical industrial plants for the control of iron (III), alkali, sulfates, other metals, and impurities [5]. These compounds have been detected on the surface of Mars; the presence of jarosite and alunite and other sulfates seems to indicate a possible presence of water on this planet [6].

On the other hand, these compounds (alunite, jarosite, and beudantite) can be used to immobilize elements such as arsenic and lead, among others. These kinds of compounds exhibit good stability under a wide range of environmental conditions; they have additionally been used for the long-term storage of toxic elements [7,8].

In general [3], numerous authors have studied different aspects of jarosites: their mineralogy, structure, formation in natural environments or through synthesis, immobilization, stability, reactivity in acid and alkaline media, and applications [9–12]. Jarosites are also formed during leaching or bioleaching processes, for example, over chalcopyrite [13].

Jarosite-type compounds have been proposed in multiple applications: pigments, building materials such as bricks, blocks, cement, tiles, and other applications. In addition, these materials have been proposed for use as fertilizers and in some battery components and also in the field of biomaterials [14].

2. Contributions

In their work, Cruells and Roca [3] developed a review of different aspects related to jarosite-type compounds: jarosite, beudantite, and alunite. This work focused on research from the last twenty years, without forgetting to examine the most relevant previous studies. The revised papers cover a wide field of study that includes natural jarosite formation, synthesis at the laboratory scale, and synthesis in industrial plants, such as in zinc hydrometallurgy, by controlling the amount of iron (III), alkali, and sulfates in solutions. This paper also includes works about the structure, thermodynamics, and reactivity of jarosites in alkaline and acid media and transformations achieved by thermal treatment. During their formation, jarosites can incorporate valuable elements (Ag, Au, and Cu) into their structure, which can be recovered, and other elements (As and Pb) considered highly dangerous for health and the environment can be immobilized in these structures.

check for updates

Citation: Cruells, M.; Roca, A. Jarosites: Structure, Formation, Leaching, Environmental, and Applications. *Metals* **2023**, *13*, 1292. https://doi.org/10.3390/met13071292

Received: 3 July 2023
Accepted: 14 July 2023
Published: 19 July 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Sufficient knowledge of the synthesis of jarosite-type compounds, in which the composition, structure, and morphology of these compounds can be controlled, opens up a very interesting field for new applications such as catalysts, fertilizers, pigments, and so forth.

A study performed by Serralde-Lealba et al. [12] on the synthesis of potassium jarosite doped with calcium, magnesium, or strontium showed that these doped materials improve cell viability and osteogenic behavior, so they could be used as biomaterials to also allow for cell proliferation with a significant impact on cell differentiation and osteogenesis. It is possible that these materials joined to polymeric materials can be functionalized to produce scaffolds with osteoinductive properties and with the possibility of replacing culture media with cell differentiation properties.

Cogram et al. [9] developed a study about the extent of silver's incorporation into structures such as potassium jarosite and sodium jarosite, at temperatures of 22, 97, and 140 °C. The synthesis products were characterized by XRD, SEM, chemical analysis, and Raman spectroscopy. The authors observed that the silver content increased with the increasing concentration of silver in the starting solutions. The study of the temperature effect indicated that higher temperatures of synthesis increased silver and alkali occupancy. The database resulting from the characterization can be useful for predicting the ability of jarosites to incorporate silver into their structure in both natural and industrial environments.

The jarosites generated in the purification and control of iron in solutions of hydrometallurgical processes present valuable elements (Au and Ag) in their structures, which must be recovered, and other elements (As, Pb, and Cr) that are considered harmful to the environment and health. The recovery of valuable elements by means of leaching jarositic waste is often linked more or less to the high dissolution of undesirable elements.

Flores et al. [11] present a kinetic study of alkaline decomposition in the NaOH medium of a solid solution of ammonium–sodium jarosite with arsenic, synthesized by the same authors, to provide information on the stability of this compound in extreme conditions of alkalinity and temperature. Under the synthesis conditions, the amount of arsenic as AsO_4^{3-} was 3.19% by weight. Decomposition, after a variable induction period depending on the temperature and the concentration of OH-, takes place according to the decreasing nucleus model with chemical control, forming a layer of iron hydroxide that adsorbs the arsenic. Sodium, ammonium, and sulfur (as sulfate) passed into the solution. The authors indicated that synthesis, developed as described, can be an alternative to the elimination of arsenic contained in water.

In their study, Picazo-Rodríguez et al. [10] examined the effect of different pretreatment methods: (1) alkaline hydrothermal pretreatment (1 M NaOH), (2) alkaline-oxidizing pretreatment (1 M NaOH/0.1 M $Na_2S_2O_8$), and (3) alkaline-oxidizing (1 M NaOH/0.1 M $Na_2S_2O_8$ 0.1) pretreatment prior to desulfurization of the residue. After pretreatment, the concentrations of Pb, As, Fe, and S were analyzed in the pretreatment liquid and in those of cyanidation (CN^- 0.06 M) or cyanidation with glycine (CN^- 0.06 M, Glycine 0.06 M, 1% H_2O_2) liquids. The results were compared with those obtained in cyanidation and with glycine-cyanidation without any pretreatment. It was found that previous alkaline treatment decreased the dissolution of arsenic and lead during cyanidation. According to the authors, the concentrations of Pb and As exceed the permissible limits in both the pretreatment and cyanidation solutions. In a previous study, the authors examine the effect of these pretreatments on the recovery of valuable metals (Au and Ag) in a residue from the leaching of chalcopyrite [15].

3. Conclusions

Jarosite, beudantite, and alunite are members of the alunite supergroup. These minerals play an important role in different fields of extractive metallurgy. Jarosite compounds are formed by weathering sulfide ores or synthesized in laboratories or industrial plants. Jarosites are also formed during chalcopyrite leaching for example. In some cases, the passivation of the leaching processes is attributed to the formation of jarosite and/or the

presence of elemental sulfur. These kinds of compounds have also been detected on the surface of Mars.

Jarosite-type compounds are also used to immobilize elements such as Pb, As, etc., contained in liquids; the solids formed can be used for the long-term storage of toxic elements. Different aspects of jarosites have been studied including their formation in natural environments or through synthesis, their mineralogy, structure, stability, immobilization practice, their reactivity in different media, and their applications.

Author Contributions: Conceptualization, M.C. and A.R.; methodology, A.R. and M.C.; writing—original draft preparation, A.R.; writing—review and editing, M.C.; visualization, M.C. and A.R.; supervision, M.C. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: As guest editors, we would like to especially thank Josie Li, section managing editor, for her support and her active role in the production of this Special Issue. We are also grateful to all staff members at the *Metals* editorial office for this valuable collaboration. We express our gratitude to all of the contributing authors and reviewers for their excellent work. We are confident that the information contained in this Special Issue about jarosite-type compounds will be of great interest to researchers working in this field. Last but not least, we want to dedicate this Special Issue "Jarosites: Structure, Formation, Leaching, Environmental, and Applications" to the memory of John E. Dutrizac (CANMET, Canada) and Joan Viñals (Universitat de Barcelona, Spain), who both sadly passed away some years ago. They were leading experts in the field of extractive metallurgy and, in particular, in the study of the precipitation, properties, and reactivity of minerals of jarosite-type compounds, as can be seen throughout this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dutrizac, J.E.; Kaiman, S. Synthesis and properties of jarosite-type compounds. *Can. Mineral.* **1976**, *14*, 151–158.
2. Jambor, J.L. Nomenclature of the alunite supergroup. *Can. Mineral.* **1999**, *37*, 1323–1341.
3. Cruells, M.; Roca, A. Jarosites: Formation, Structure, Reactivity and Environ-mental. *Metals* **2022**, *12*, 802. [CrossRef]
4. Smith, A.M.L.; Hudson-Edwards, K.A.; Dubbin, W.E.; Wright, K. Dissolution of jarosite [$KFe_3(SO_4)_2(OH)_6$] at pH 2 and 8: Insights from Batch Experiments and Computational Modelling. *Geochim. Cosmochim. Acta* **2006**, *70*, 608–621. [CrossRef]
5. Hoeber, L.; Steinlechner, S. A comprehensive review of processing strategies for iron precipitation, residues from zinc hydrometallurgy. *Clean. Eng. Technol.* **2021**, *4*, 100214. [CrossRef]
6. Potter-McIntyre, S.L.; McCollom, T.M. Jarosite and Alunite in Ancient Terrestrial Sedimentary Rocks: Reinterpreting Martian Depositional and Diagenetic Environmental Conditions. *Life* **2018**, *8*, 32. [CrossRef] [PubMed]
7. Hudson-Edwards, K.A. Uptake and release of arsenic and antimony in alunite–jarosite and beudantite group minerals. *Am. Mineral.* **2019**, *104*, 5. [CrossRef]
8. Viñals, J.; Sunyer, A.; Torres, E.; Beltran, V.; Llorca, N. Arsenic inertization from copper pyrometallurgy through phases of the alunite supergroup. *World Metall.-Erzmetall* **2010**, *63*, 310.
9. Cogram, P.F.; Welch, M.D.; Hudson-Edwards, K.A. Uptake of Silver by Jarosite and Natrojarosite Family Compounds at 22 °C, 97 °C and 140 °C. *Metals* **2023**, *13*, 627. [CrossRef]
10. Picazo-Rodríguez, N.G.; Soria-Aguilar, M.d.J.; Chaidez, J.; Flores, M.; Almaguer-Guzmán, I.; Carrillo-Pedroza, F.R. Analysis of the Behavior of As and Pb during the Pretreatments Applied to a Jarosite Residue for the Recovery of Gold and Silver. *Metals* **2023**, *13*, 138. [CrossRef]
11. Flores, V.H.; Patiño, F.; Roca, A.; Flores, M.U.; Reyes, I.A.; Reyes, M.; Islas, H. Alkaline Decomposition of Solid Solution of Ammonium-Sodium Jarosite with Arsenic. *Metals* **2022**, *12*, 584. [CrossRef]
12. Serralde-Lealba, J.R.; Cerecedo-Sáenz, E.; Hernández-Ávila, J.; Arenas-Flores, A.; Veloz-Rodríguez, M.A.; Gutiérrez-Amador, M.d.P.; González-González, A.M.; Rosales-Ibáñez, R.; Salinas-Rodríguez, E. Doped Potassium Jarosite: Synthesis, Characterization and Evaluation as Biomaterial for Its Application in Bone Tissue Engineering. *Metals* **2022**, *12*, 1052. [CrossRef]
13. Córdoba, E.M.; Muñoz, J.A.; Blázquez, M.L.; González, F.; Ballester, A. Comparative kinetic study of the silver-catalyzed chalcopyrite leaching at 35 °C and 68 °C. Int. *J. Miner. Process.* **2009**, *92*, 137–143. [CrossRef]

14. Eftekhari, N.; Kargar, M.; Zamin, F.R.; Rastakhiz, N.; Manofi, Z. A review on various aspects of jarosite and its utilization potentials. *Ann. Chim. Sci. Mater.* **2020**, *44*, 43–52. [CrossRef]
15. Garza, M.; Carrillo, F.; Picazo, N.; Soria, M.; Almaguer, I.; Cháidez, J. Effects of pretreatment and leaching medium on the extraction efficiency of Au and Ag from a chalcopyrite leaching by-product. *Dyna* **2021**, *88*, 119–126. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.