

Analysis And Extraction Of Mineral Content From Guano In Karst And Non Caves.

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Abstract

The objective of this study is to conduct a comprehensive characterization of guano from cave and non-cave environments through a series of mineralogical and chemical analyses. The methodology employed includes X-Ray Fluorescence (XRF) analysis to determine the chemical elemental composition, X-Ray Diffraction (XRD) for mineral phase identification, and Scanning Electron Microscopy (SEM) for morphological observation. The specific objectives of this study are as follows: (1) to analyze the comparison of magnetic mineral properties, (2) to analyze the chemical element composition, (3) to analyze the types and distribution of magnetic mineral phases, and (4) to analyze the morphological differences between cave and non-cave guano. The guano samples were obtained from the Bat Cave Karst Area in Rammang-Rammang, Maros Regency, while the non-guano samples were collected from the Soppeng Bat Park. Results indicate that cave guano has significantly higher magnetic susceptibility values ranging from $278.0 \times 10^{-8} \text{ m}^3/\text{kg}$ to $832.7 \times 10^{-8} \text{ m}^3/\text{kg}$, compared to non-cave guano, which ranges from $23.7 \times 10^{-8} \text{ m}^3/\text{kg}$ to $51.1 \times 10^{-8} \text{ m}^3/\text{kg}$. The elemental composition is generally similar in both guano types, however, non-cave guano lacks vanadium (V). XRD analysis revealed a greater diversity of mineral phases in cave guano than in non-cave guano. SEM confirmed significant morphological differences, with cave guano showing a denser and more uniform microstructure compared to the more heterogeneous structure in non-cave guano. This study provides new insights into the environmental influences on guano composition and physical properties, which may assist in agricultural applications and environmental research.

Keywords: Guano, Karst, Cave, SEM, XRF, XRD, Magnetic Minerals, Magnetic Susceptibility.

INTRODUCTION

Magnetic minerals are important minerals in many industries and engineering, including magnetite (Fe_3O_4), hematite ($\alpha\text{-Fe}_2\text{O}_3$), maghemite ($\gamma\text{-Fe}_2\text{O}_3$) in photocopiers and laser printers (Yulianto, et al., 2002). The black magnetite mineral is used as an ingredient in dry ink (toner), red hematite is used as a dye, while maghemite is often used in the biomedical field of magnetic recording media and nanoparticle technology, namely in the treatment of cancer cells by hyperthermia. Based on this use, the demand for magnetic minerals in various fields has increased, especially in the industrial field (Pankhurst et al., 2003).

The need for magnetic minerals is increasing as time goes by. However, the availability of magnetic minerals in nature is decreasing. The need for a large number of magnetic minerals is not proportional to the presence of magnetic minerals available in nature. According to (Tarling

& Hrouda, 1993), the existence of magnetic minerals in nature is found in rocks. In igneous and metamorphic rocks, the magnetic minerals contained in them are only 5% of the overall mass of the rock even lower, but still significant for many sediments.

Cave sediments consist of two categories, namely chemical sediments and clastic sediments. Chemical sediments are sediments that form in caves such as stalagmites and stalagmites. Clastic sediments are sediments that are carried from the outside environment into caves. One example of a clastic sediment is guano. Guano, bird droppings that accumulate in caves, contain a large amount of information related to the environmental conditions of the cave and the fauna that inhabit it. In particular, the analysis of the magnetic mineral content of guano can provide insight into the geological history, elemental composition, and processes in the cave environment. Comparisons between karst and non-karst cave guano can reveal geochemical differences and the influence of cave conditions on the formation of magnetic minerals (Ford & Williams, 2007).

(Sambolangi, 2021) has measured magnetic susceptibility and obtained the concentration of guano magnetic minerals from the Bat Cave ranging from 7.2×10^{-8} m3/kg to 147.6×10^{-8} m3/kg. This shows that guano contains magnetic minerals. The presence of magnetic minerals in guano can come from bat food. In addition, the presence of magnetic minerals in guano also comes from dust, where the dust is brought from the outside environment into the cave. Natural caves where bats live are very much found in karst areas (Sambolangi, 2021).

The magnetic susceptibility of guano can reflect the complex interactions between organic materials and minerals in caves. High or low magnetic mineral content can indicate variations in the sedimentation process, the influence of groundwater, and climate change around the cave. Magnetic susceptibility analysis is important in detecting changes in the cave environment that may be influenced by internal and external factors. The magnetic susceptibility of guano can be considered an indicator of sensitivity to environmental changes. Differences in magnetic susceptibility between karst and non-karst cave guano may reflect differences in hydrological conditions, climate, or mineral resources around the cave (John Wiley & Sons. Goldscheider, N., & Drew, 2007).

Multi-method approaches, including magnetic susceptibility, XRF, XRD, and SEM, are essential for gaining a holistic understanding of karst and non-karst cave environments. This combination of methods allows for the integration of rich data to answer complex questions about the history, geology, and environment of caves.

Elemental content analysis using XRF allows for the identification of key elements and traces that can provide clues about the material's provenance. XRF (X-ray Fluorescence) analysis is a non-destructive method that can identify the composition of chemical elements in a sample. The application of XRF to both karst and non-karst cave guano can provide an in-depth understanding of the dominant elements and the potential for significant differences between the two environments.

Identification of mineral phases through XRD analysis helps to describe the guano formation process and cave environment in more detail. An understanding of the types of magnetic and non-magnetic minerals can provide insights into the dynamics of karst environments and changes over time.

The use of SEM can reveal the morphology of particles. This information can be used to identify signs of biological or chemical influences affecting mineral formation in both karst and non-karst cave guanos.

A better understanding of the magnetic minerals in guano could contribute to the conservation efforts of guano and the karst environment. By knowing the characteristics of minerals, guano management practices can be formulated to minimize the impact on the natural environment. A comparison of the characteristics of magnetic minerals in karst and non-karst cave guano can provide information about the environmental factors that distinguish these two sites. This analysis becomes relevant for understanding the biogeochemical and geological differences between caves with and without influences.

The analysis of the magnetic mineral content of guano karst caves and non-karst caves can open up the potential for new discoveries in guano science, karst geology, and mineralogy. This research can yield new knowledge about cave dynamics and deepen our understanding of the complex interactions between organisms, groundwater, and minerals in cave environments (Baker, 2005).

Based on this background, further research to find out the comparison of guano quality between karst guano and non-karst guano, with the title "**Analysis and Extraction of Guano Mineral Content from Karst and Non-Cave Caves**".

The objectives to be achieved in this study are to analyze the comparison of magnetic mineral properties between karst cave guano and non-karst cave guanos, analyze the comparison of chemical element composition in karst cave guano and non-karst cave guano can be identified through XRF analysis, analyze the type and phase distribution of magnetic minerals that can be found in karst cave guano and non-karst cave guano based on XRD analysis, and to analyze the differences in morphological characteristics in karst cave guano and non-karst cave guano that can be observed through SEM analysis.

So the benefit of this study is to determine the Mineral Composition: Identify and analyze the types of minerals contained in guano from karst caves and non-karst caves. This can provide insight into the differences in mineral composition between the two environments. Understanding the Effects of Karst Environment: Researching how the karst environment can affect the mineral content in guano. Factors such as karst geology and the chemical processes that occur in it may have a significant impact on the minerals formed in guano. Measuring Environmental Health: Guano analysis can also provide information about the health of the environment around the cave. The mineral content in guano can reflect the nutritional status and ecosystem of the area. Understanding Ecology: Examining how the mineral content in guano can affect local ecosystems. This can provide a better understanding of the interactions between guano-producing animals, vegetation, and other organisms in the environment.

By investigating these aspects, this research is expected to contribute to the scientific understanding of guano, karst environment, and ecosystem health in general.

METHODOLOGY

The research carried out is quantitative descriptive research, quantitative descriptive research is to collect field data and laboratory data, where field data is obtained from conducting direct surveys in the field, while laboratory data is obtained from sample testing.

The research was conducted for 6 months from December 2023 to May 2024. Figures 3.1 and 3.2 show a map of the location of Guano sampling from Bat Cave in the Rammang-Rammang Maros Karst Area and in Soppeng Regency

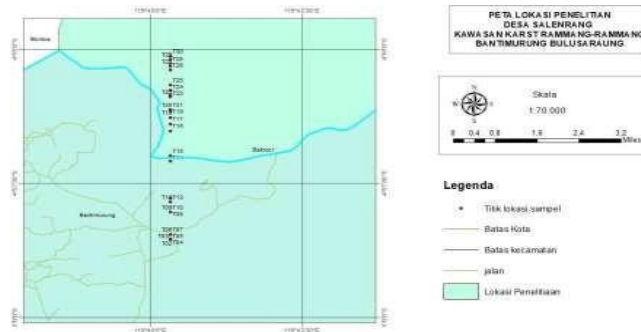


Figure 1 Geological Map of the Research Location

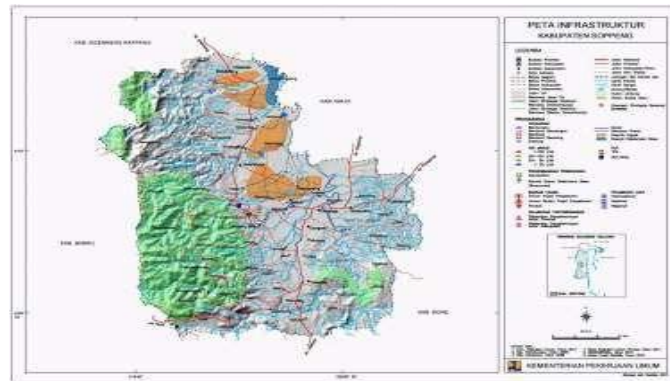


Figure 2 Geological Map of Soppeng Regency

(<https://peta-kota.blogspot.com/2017/03/peta-kabupaten-soppeng.html>)

Object location is performed:

1. The location of sample preparation, extraction, and synthesis was carried out in the Physics Laboratory of the Department of Physics, State University of Makassar.
2. The magnetic susceptibility testing of samples using the Bartington MS2B was carried out at the Laboratory of Geophysical Engineering and Mining Engineering, Faculty of Earth Sciences and Technology, Haluoleo University.
3. Fluorescence X-ray (XRF) characterization testing was carried out at the Chemistry Laboratory of Padang State University.
4. X-Ray Diffraction (XRD) characterization testing was carried out in the Material Characterization Division, Department of Materials Engineering, Sepuluh Nopember Institute of Technology.
5. Scanning Electron Microscopy (SEM) characterization testing was carried out in the Materials Characterization Division, Department of Materials Engineering, Sepuluh Nopember Institute of Technology.

RESULTS AND DISCUSSION

1. Magnetic Suptivity Value of Guano Cave and Non Cave

Table 1 Magnetic Susceptibility Measurement Results of Guano Cave and Non-Cave Samples

No.	Kode Sampel	Nilai Suseptibilitas		
		$\chi_{LF} (10^{-8} \text{ m}^3/\text{kg})$	$\gamma_{HF} (10^{-8} \text{ m}^3/\text{kg})$	$\gamma_{LF} (\%)$
1	G/R-01	764.2	761.7	0.33
2	G/R-02	774.6	767.0	0.98
3	G/R-03	832.7	826.0	0.80
4	G/R-04	424.7	423.3	0.33
5	G/R-05	422.5	420.5	0.47
6	G/R-05	627.1	623.8	0.53
7	G/R-06	488.6	486.0	0.53
8	G/R-08	325.8	323.9	0.58
9	G/R-09	278.0	276.2	0.65
10	G/R-10	747.0	742.0	0.67
11	G/S-01	40.9	38.9	4.89
12	G/S-02	49.3	46.1	6.49
13	G/S-03	32.2	30.5	5.28
14	G/S-04	23.7	22.4	5.49
15	G/S-05	44.2	40.4	8.60
16	G/S-06	51.1	47.9	6.26
17	G/S-07	45.6	42.3	7.24
18	G/S-08	50.5	46.2	8.51
19	G/S-09	45.0	43.9	2.44
20	G/S-10	45.2	42.7	5.53

The value of the magnetic susceptibility measurement results can be seen in table 4.1. Guano samples of the cave have a magnetic susceptibility value range of $278.0 \times 10^{-8} \text{ m}^3/\text{kg}$ to $832.7 \times 10^{-8} \text{ m}^3/\text{kg}$. Meanwhile, the non-cave guano samples have a magnetic susceptibility value range of $23.7 \times 10^{-8} \text{ m}^3/\text{kg}$ to $51.1 \times 10^{-8} \text{ m}^3/\text{kg}$.

The magnetic susceptibility values in Caves and Non-caves vary or are not constant and are presented in the form of graphs in figure 4.1. The abundance of magnetic minerals in cave guano is in sample 3, while in non-cave guano is in sample 8.

In Figure 3, it can be seen that the lowest magnetic susceptibility value of non-cave guano is in the S04 sample of $23.7 \times 10^{-8} \text{ m}^3/\text{kg}$ and the highest magnetic susceptibility value is in the S06 sample of $51.1 \times 10^{-8} \text{ m}^3/\text{kg}$.

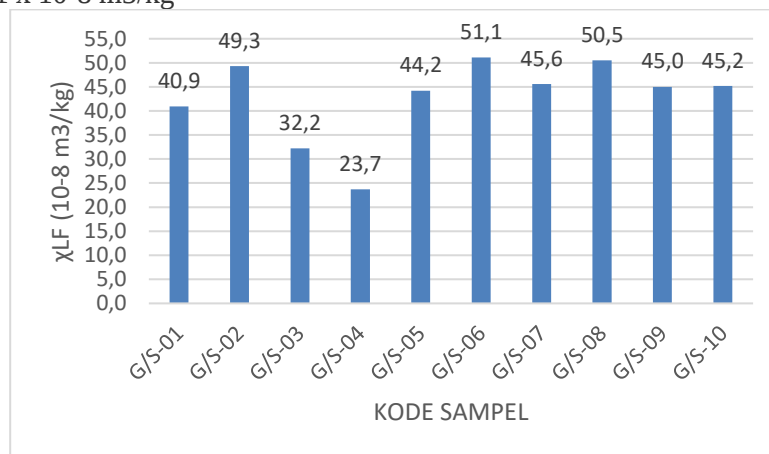


Figure 3 Magnetic Susceptibility Value at Low Frequency (χ_{lf}) Guano Sample in Non-Cave

In Figure 4, it can be seen that the lowest magnetic susceptibility value of non-cave guano is in the R09 sample of $278.0 \times 10^{-8} \text{ m}^3/\text{kg}$ and the highest magnetic susceptibility value is in the R03 sample of $832.7 \times 10^{-8} \text{ m}^3/\text{kg}$.

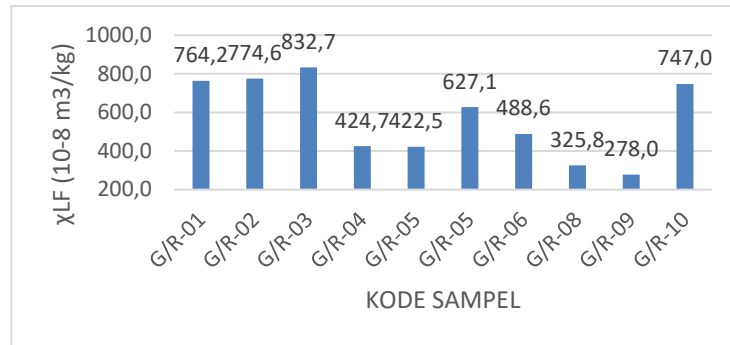


Figure 4 Magnetic Suceptibility Value at Low Frequency (Xlf) Guano Sample in Cave

2. Guano Cave and Non Cave element content

Characterization using X-Ray Fluorescence (XRF) was carried out to determine the mineral element content in 10 guano samples and 10 non-guano samples. The results of the characterization are as follows.

Table 2 Composition of Guano Cave and Non-Cave Elements

KODE SAMPEL	Komposisi Unsur (%)								
	V	Mn	P	Mg	Al	K	Fe	Si	Ca
R1	0.107	0.435	2.86	7.047	5.993	8.993	25.677	21.474	24.276
R2	0.101	0.457	2.954	7.216	4.031	5.244	27.663	15.113	34.281
R3	0.099	0.404	2.841	6.494	5.909	7.124	28.043	19.816	26.29
R4	0.063	0.341	2.112	5.435	2.816	3.97	16.633	9.452	57.362
R5	0.094	0.461	3.202	9.689	3.852	5.648	25.2	12.968	34.56
R6	0.053	0.554	2.241	5.505	5.626	10.847	16.044	23.053	34.462
R7	0.084	0.436	2.926	6.177	5.197	5.258	24.865	17.691	34.597
R8	0.083	0.474	2.563	6.774	4.002	4.804	23.685	14.648	40.607
R9	0.06	0.3	1.922	7.569	2.344	2.736	15.367	7.144	60.864
R10	0.092	0.362	2.447	6.347	5.542	5.58	25.558	18.891	32.395
S1	0	1.081	12.008	6.606	2.907	0.593	11.273	3.899	58.915
S2	0	1.172	12.47	7.228	3.055	0.715	13.503	3.854	54.902
S3	0	1.219	12.457	8.43	2.682	0.825	11.09	3.695	56.116
S4	0	1.182	11.943	8.254	2.528	2.128	10.646	4.065	56.123
S5	0	1.163	11.991	9.222	2.808	0.684	12.572	3.736	54.541
S6	0	1.075	11.679	7.378	3.205	0.959	13.83	4.506	54.178
S7	0	1.019	11.867	7.013	3.062	0.842	13.008	4.722	55.712
S8	0	1.016	11.97	6.404	4.3	1.131	13.548	7.808	50.945
S9	0	0.967	11.208	6.474	2.949	0.657	10.888	4.183	60.101
S10	0	1.066	12.217	7.265	2.939	0.696	12.63	4.56	55.796

XRF (X-ray Fluorescence) analysis is a non-destructive chemical analysis technique used to quantitatively determine the elemental content in a sample. In this context, XRF analysis has been carried out on 20 guano samples to identify and measure the content of certain elements in the material.

The results of the analysis showed that although the content of major elements such as nitrogen (N), phosphorus (P), and potassium (K) tended to be stable among the samples, there was a significant variation in the concentrations of minor elements such as calcium (Ca) and magnesium (Mg) among the guano samples.

This variation can be due to a number of factors, including the age of the guano, the type of food consumed by the bats, and the environmental conditions in which the guano is formed. For example, older guano may have different elemental compositions due to the decomposition process that occurs over time.

Interestingly, although there is variation between cave and non-cave guano samples, there are several elements that are consistently present in both types of guano, such as manganese (Mn), phosphorus (P), magnesium (Mg), aluminum (Al), potassium (K), iron (Fe), silicon (Si), and calcium (Ca).

However, it should be noted that there are significant differences between the two types of guano. For example, the element vanadium (V) was found in guano samples of caves, while it was not found in non-cave guanos. In addition, nickel (Ni) was not found in any of the guano samples (R6 code sample), indicating a marked variation in the elemental composition among the guano samples.

From the results of this analysis, it can be concluded that the element calcium (Ca) dominates the elemental concentration in cave and non-cave guano samples, followed by the element iron (Fe). In addition, the results of the XRF test are related to the magnetic susceptibility value where the R3 code has the highest magnetic susceptibility value, at the concentration of elements from the XRF test the Fe content which has the largest concentration.

3. Identification of Guano Cave and Non-Cave Mineral Phases

a. Types of Guano Cave and Non-Cave Minerals

Characterization using X-Ray Diffraction (XRD) was carried out to determine the mineral element content in 5 selected samples of Guano Gua and 5 selected samples of Guano Non-Guano. The results of the characterization are as follows

Figure 5 shows the XRD patterns for guano powder samples. In the image, it can be seen that the phases formed are O2Si, MgO3Si, P4O10, CaO17P6, FeKO2, NNaO3, and CCaO3

Analysis of the XRD results in Figure 4.4 reveals characteristic patterns indicating the presence of various mineral phases in the non-cave guano powder samples. The phases detected O2Si, MgO3Si, P4O10, CaO17P6, FeKO2, NNaO3, CCaO3, C5CaO5, AlO4P, Fe2K2O4, MnO2, Fe4O5, O2V and FeO provide in-depth insight into the mineral composition and chemical structure of the samples. Further analysis can be carried out to understand the crystallographic characteristics and physicochemical properties associated with each phase of the detected mineral.

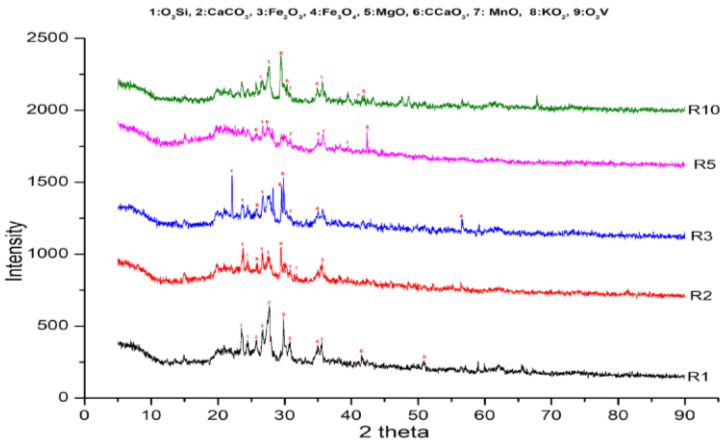


Figure 5 Diffractogram of Guano Sample of Cave

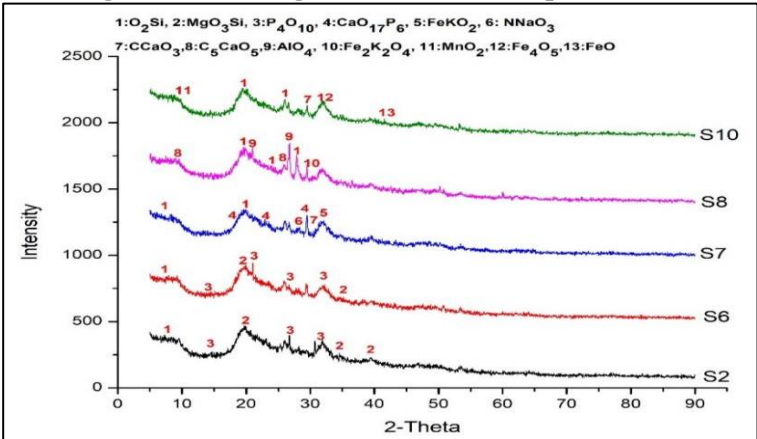


Figure 6 Diffractogram of Guano Sample from Non-Cave

b. Sample Phase Composition

Table 3 Mineral Phase Composition of Guano Cave Samples

No.	Sample Name	Sample Composition	Chemical formula	Presented (%)
1.	R1	SiO2	O2Si	51.7

			Na2Si	11.9
		Quartz	O2Si	8.9
		Ca(CO3)	C Ca O3	7.8
		Magnetite	Fe3O4	6.0
		Tridymite	O2Si	4.7
			K O2	4.2
		Periclase	Mg O	1.9
2.	R2	Quartz	O2Si	48.3
		Calcite	C Ca O3	21.7
			Mn O	17.0
		Maghemite	Fe2O3	11.0
			KO2	2.0
3.	R3	Quartz	O2Si	46.9
		Vaterite	C Ca O3	21.0
		Magnetite	Fe3O4	11.9
		Calcite	C Ca O3	10.1
			Mn O	10.0
4.	R5	Quartz	O2Si	49.8
			O2V	19.1
		Periclase	Mn O	18.2
		Magnetite	Mg O	12.2
		Calcite	Fe3O4	11.3
			C Ca O3	8.4
5.	R10	Calcite	C Ca O3	37.3
		Periclase	Mg O	25.4
		Quartz	O2Si	12.2
		Magnetite	Fe3O4	8.2
		SiO2	O2Si	7.2
		Magnetite-h	Fe3O4	6.9
		Manganosite	Mn O	2.9

In Table 3, it can be seen that the phase composition of the guano cave sample has a different composition for each sample, but each sample has Quartz minerals where the highest percentage is located in the R5 sample.

Table 4 Mineral Phase Composition of Non-Cave Guano Samples

No.	Sample Name	Sample Composition	Chemical formula	Presentase(%)
1.	S2	P ₂ O ₅	O ₅ P ₂	70.7
		Magnesium oxide periclase	Mg O	24.7
		Calcite	C Ca O ₃	4.6
2.	S6	Pyroxene-ideal	Mg O ₃ Yes	51.5
		P ₄ O ₁₀	O ₁₀ P ₄	46.7
		SiO ₂	O ₂ Yes	1.7
3.	S7	Ca ₂ (P ₆ O ₁₇)	En ₂ O ₁₇ P ₆	35.0
		K Fe O ₂	Fe K O ₂	28.9
		SiO ₂	O ₂ Yes	19.4
		Sodium nitrate nitratine	N Na O ₃	15.5

4.	S8	<i>CaCO₃</i>	C Ca O ₃	1.2
		<i>SiO₂</i>	O ₂ Yes	30.9
		<i>Magnesium thiosulfate</i>	H ₁₂ Mg O ₉ S ₂	28.5
		<i>hexahydrate</i>	C ₅ Ca O ₅	17.6
			Al O ₄ P	14.2
		<i>Al (P O₄)</i>	Fe ₂ K ₂ O ₄	8.8
5.	S10	<i>K₂ (Fe₂ O₄)</i>		
			O ₂ Yes	40.2
		<i>SiO₂</i>	O ₂ Yes	23.4
		<i>Calcite</i>	C Ca O ₃	14.0
		<i>Todorokite</i>	Mn O ₂	11.3
			Fe ₄ O ₅	8.7
		<i>Iron Oxide Wuestite</i>	Fe O	2.4

In Table 4, it can be seen that the phase composition of the guano cave sample has a different composition for each sample, but each sample has a dominant SiO₂ mineral where the highest percentage is located in the S8 sample.

4. Morphology of Guano Cave and Non-Cave Particles

Characterization using SEM aims to see the surface morphology of guano materials. From the results of the guano sample test, 1 sample with code R3 at the Cave location and code S7 at the non-Cave location was taken to test the microstructure. From the SEM photo, there is a photo of a guano sample with a magnification of 1250x.

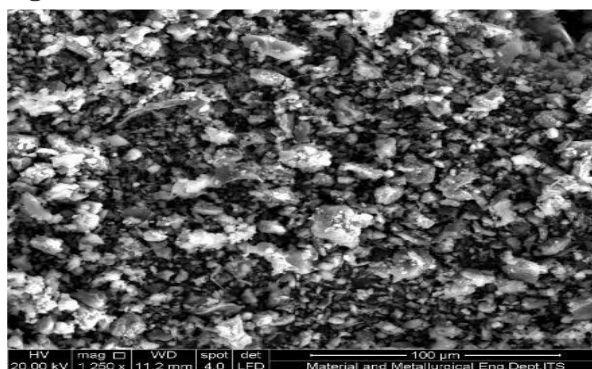


Figure 7 Microstructure of Guano Sample Code R3 at Cave Location with 1250x magnification

Figure 4.5 shows the surface structure of a guano sample with the code R3 at 1250x magnification. This image shows the rough and grainy surface of the observed material. Various particles of varying sizes and shapes can be seen. The particles appear to have a non-homogeneous texture, with some areas appearing lighter and darker areas.

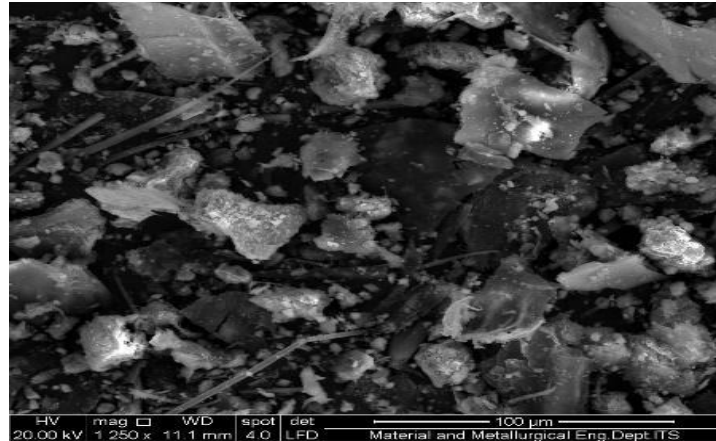


Figure 8 Microstructure of Guano Sample Code S7 in Non-Cave Locations with 1250x Magnification

Figure 8 shows the surface structure of a guano sample with the code S7 at 1250x magnification. This image shows the surface of the material consisting of particles of varying sizes and shapes. Some particles look larger and have a smoother surface, while others are smaller and rougher. There are visible particles that appear lighter, which may indicate a material with a different density or composition compared to darker particles. The surface of the material appears heterogeneous, indicating variations in the size, shape, and possibly chemical composition of the particles.

Discussion

1. Magnetic Suptivity Value of Guano Cave and Non Cave

Magnetic susceptibility measurements in guano samples were performed using a Bartington MS2 Susceptibility Meter with an MS2B sensor operating at two frequencies, namely 470Hz and 4700Hz. The measurement results showed that high magnetic susceptibility at low frequencies indicated the presence of a higher magnetic mineral content in the guano sample. The value of magnetic susceptibility at low frequencies is consistently higher than at high frequencies. Measurements at both frequencies are performed in a constant magnetic field and are typically used to detect ultrafine-ferrimagnetic minerals, including superparamagnetic and single-domain particles. Measurements at low frequencies allow for the detection of superparamagnetic particles due to slower changes in the magnetic field compared to the relaxation time of superparamagnetic particles. Therefore, magnetic susceptibility at low frequencies tends to be lower than at high frequencies.

Non-cave guano samples have a fairly low range of magnetic susceptibility values ranging from 23.7×10^{-8} m³/kg to 51.1×10^{-8} m³/kg, indicating that the guano has a relatively low magnetic mineral content. This is due to the different environmental conditions in which the guano is formed, which may not contain much material that can provide high magnetic susceptibility. Meanwhile, cave guano samples have a fairly high range of magnetic susceptibility values, namely 278.0×10^{-8} m³/kg to 832.7×10^{-8} m³/kg, indicating the presence of higher magnetic mineral content in the guano. The highest abundance of magnetic minerals in cave guano was in the R03 sample, while the highest non-cave guano was in the S06 sample. Higher magnetic susceptibility values in cave guano indicate a greater abundance of magnetic minerals, which may be due to more stable environmental conditions in the cave. Guano caves tend to have stronger magnetic properties, which may be due to environmental conditions within the cave that allow the accumulation of magnetic minerals from nearby rocks or different geological processes.

Based on the mineral classification according to the (Dearing, 1994), it shows that a high value of magnetic susceptibility indicates the accumulation of magnetic minerals with a fairly high concentration or amount. The general classification of magnetic suseptivity based on the Dearing table, in guano samples caves is included in the ferromagnetic category. This indicates that the sample has a strong response to external magnetic fields and may contain significant

concentrations of ferromagnetic minerals such as magnetite. However, non-cave guano samples have magnetic susceptibility which is included in the paramagnetic category. This suggests that the sample tends to be attracted into the external magnetic field, but the response is relatively weak compared to ferromagnetic materials (Dearing, 1994).

In a study conducted by (Arsyad et al., 2022) related to guano in Bat Cave, it was found that the magnetic susceptibility range in the guano ranged from 7.2×10^{-8} m³/kg to 147.6×10^{-8} m³/kg. The results of this study showed that the magnetic susceptibility value in the guano was relatively low, comparable to that of non-cave guano samples. However, there is a significant difference with the susceptibility value of guano in the cave which has a high value range. This indicates the possibility of contamination by impurity substances derived from the activities of other living things that enter the cave. The study indicates that the presence of other living things in the cave can affect the composition of the guano and result in significant differences in magnetic susceptibility values. Therefore, further research is needed to understand more deeply the factors that affect the composition of guano in caves and their impact on magnetic susceptibility values.

2. Guano Cave and Non Cave element content

XRF analysis has been used to determine the elemental content in 20 guano samples with the aim of understanding the elemental composition in the material. The results of the analysis showed significant variations in the concentration of elements between guano samples. Although major elements such as nitrogen (N), phosphorus (P), and potassium (K) tend to be stable, there are marked differences in the concentrations of minor elements such as calcium (Ca) and iron (Fe).

Variations in the concentration of elements in guano can be affected by a variety of factors. The age of the guano, the type of food consumed by the bats, and the environmental conditions in which the guano is formed are some of the factors that can cause such variations. The geochemical processes in guano itself can also affect the composition of the elements in guano samples. Although there is variation between cave and non-cave guano samples, there are some elements that are consistently present in both types of guano. Elements such as manganese (Mn), phosphorus (P), magnesium (Mg), aluminum (Al), potassium (K), iron (Fe), silicon (Si), and calcium (Ca) are found in both types of guano.

However, there are significant differences between the two types of guano. For example, the element vanadium (V) was found only in guano samples of caves. One of the causes of the appearance of vanadium elements in cave guano may be related to environmental contamination. The presence of vanadium in karst caves may reflect different weathering processes and interactions with groundwater compared to non-cave environments. In addition, the higher magnesium and potassium content in guano caves may indicate that karst caves provide more stable and nutrient-rich conditions for the formation of certain minerals. The location of the cave adjacent to the Tonasa cement mine allows environmental contamination by heavy metals used or processed in the mine.

Vanadium is one of the heavy metals that is often found in mineral mines. In addition, the process of water and air flow can carry heavy metal particles from cement mines to the surrounding environment, including into caves and finally into guano produced by bats. This may explain why the element vanadium was found in guano samples of the cave. In addition, the element calcium (Ca) dominates the elemental concentration in both types of guano, followed by the element iron (Fe).

The presence of iron (Fe) in guano samples can be explained by several factors, including the origin and composition of the food consumed by bats, the organic decomposition process, and the environmental conditions in which guano is formed. Bats generally feed on different types of insects, fruits, nectar, and in some cases, the blood of animals or fish. Some of these food sources contain varying amounts of iron. For example, insects, especially blood-containing insects (such as mosquitoes), have a fairly high iron content. As a result, when bats consume this food, the element iron will be contained in their feces, which is the main component of guano.

The digestive process in the bat's body can affect the absorption and processing of iron elements from the food consumed. Although iron is an essential element for life, the bat's body only requires a small amount. Therefore, most of the iron in the food consumed can be excreted through the feces. This means that guano can contain the remains of the element iron that is not fully absorbed by the bat's body. In addition, the presence of iron in guano can also be caused by environmental contamination. If the environment around guano is polluted with iron metal, either through human activities or natural processes, then iron can enter guano through the process of absorption by the soil or by plants consumed by bats.

3. Identification of Guano Cave and Non-Cave Mineral Phases

Characterization research using X-Ray Diffraction (XRD) has been carried out to identify the mineral element content in 5 selected guano samples and 5 selected samples of non-cave guanos. This analysis is important because guanos, especially cave guanos, are a rich source of nutrients and can provide insight into the environment in which guano is formed, as well as the interactions between bats and their environment.

The XRD patterns seen in Figure 4.3 provide information about the mineral phases that form in the guano samples of the cave studied. Some of the phases detected include O₂Si, MgO₃Si, P₄O₁₀, CaO₁₇P₆, FeKO₂, NNaO₃, and CCaO₃. The interpretation of these phases provides valuable insights into the mineral composition of guano caves.

The influence of the location of the sample in the karst area can affect the mineral composition in guano. Karst is a type of landscape formed by the process of rock dissolution, and cave guano is often formed within karst caves. This dissolution process can result in chemical changes in the cave environment, which in turn can affect the mineral composition of guano. For example, minerals such as calcium carbonate (CaCO₃) can be found more often in guano formed in karst caves because aqueous solutions containing calcium carbonate can leave mineral residues when they evaporate, forming guano.

In addition, the food consumed by bats can also affect the composition of minerals in guano. Bats, as guano producers, tend to eat a wide variety of foods, including insects, fruits, and nectar. The mineral composition of these foods can be reflected in their guano. For example, if bats eat phosphorus-rich insects, their guano will likely contain phosphate minerals as observed in XRD analysis (such as P₄O₁₀ or CaO₁₇P₆).

The analysis of the XRD results in Figure 4.4 shows that various phases of minerals can be clearly identified. The phases detected, such as O₂Si, MgO₃Si, P₄O₁₀, CaO₁₇P₆, FeKO₂, NNaO₃, CCaO₃, C₅CaO₅, AlO₄P, Fe₂K₂O₄, MnO₂, Fe₄O₅, and FeO, provide an in-depth understanding of the mineral composition in the sample.

The presence of these mineral phases indicates the complexity of the organic and inorganic components in non-cave guano samples. The importance of using the XRD technique in this analysis is its ability to identify specific mineral compositions in samples with high accuracy.

The differences in mineral phases between karst and non-cave guano reflect the different environmental conditions under which guano forms and accumulates. The more enclosed and stable environment of karst caves allows for the deposition and formation of certain minerals such as vanadium oxide and magnesium silicate in higher concentrations. On the other hand, non-cave guano show a predominance of calcium carbonate, which reflects the influence of the external environment rich in carbonate rocks.

The presence of mineral phases such as silicon oxide and phosphate in both types of guano suggests that guano, regardless of its origin, contains mineral components that are essential for a wide range of applications, including in agriculture as a source of nutrients. However, differences in the concentration and type of minerals between cave and non-cave guano suggest potential differences in the efficiency and effectiveness of their use.

The influence of non-cave locations, where guano samples were obtained, is also an important factor in the chemical composition of the samples. Human activity at the site can introduce a variety of additional compounds that are reflected in the phases of the detected

minerals. For example, the presence of NNaO_3 , may come from the use of fertilizers or other organic materials that can affect the composition of the sample.

In cave and non-cave guano samples have the same compound, namely SiO_2 , the presence of SiO_2 in cave guano and cave is related to contamination from karst rocks where the research location in Maros and Soppeng is a karst area. Karst rocks, which are generally formed by the deposition of calcium carbonate (CaCO_3) dissolved by water, often contain minerals such as quartz that contain silicon dioxide. This is quite different from the research conducted by (Pahmiansyah et al., 2013) which showed the results of the study using XRD that the guano samples in Liang Besar Cave contain a lot of silicon oxide, tritium hydrogen, bisulfate, titanium (III) nitride (NTi), picotpaule and other minerals. In the research conducted by (Niarti et al., 2013) on guano in Solek Cave and Chain Cave showed the results of testing using XRD that the mineral content contained was in the form of magnetite and hematite. Meanwhile, a study conducted by (Sambolangi et al., 2024) on the bat cave guano in the Rammang-Rammang Karst Area showed that the results of XRD testing showed that the mineral content contained was in the form of Calcium Indium, Aluminum, Calcium Silicone, and Potassium. This suggests that each guano from a different cave has a different mineral content.

Based on (Hayanti & Yuliani, 2014), that bat guano has macroelements Nitrogen, Phosphorus, Potassium, Potassium, and micro elements such as Mg, Mn, Fe, Zn, Cl, and Pu. In guano samples in Bat Cave there are macro elements, namely Potassium and Nitrogen. Meanwhile, other mineral elements are classified as silicate complexes. Based on Greenwood, Norman N.; (Greenwood & Earnshaw, 2012), in the book —Chemistry of the Elements which says that Complex Silicate is a mineral consisting of silicon atoms or oxygen, so Aluminum Calcium Silicon is classified as Complex Silicate.

4. Morphology of Guano Cave and Non-Cave Particles

Characterization studies using SEM have been conducted to identify cave and non-cave guano morphology. In Figure 4.5 and Figure 4.6, the morphology of the guano with 1250x magnification is seen, where there is a difference between the microstructure of the R3 and S7 code guano samples. Nonetheless, they both have a heterogeneous and coarse microstructure with many small-sized particles that are aggregated and enclosed by non-magnetic elements. This factor is likely influenced by the sieving process using a 200 mesh sieve, where the resulting grains are very small and may not be evenly dispersed when fed into the SEM, resulting in an uneven distribution of the SEM image results.

The morphological structure of guano at 1250x magnification in the R3 code sample has a more uniform morphology and is denser with finer particles. Based on the results of XRF testing, the relatively high iron (Fe) content indicates that these fine particles could be iron-rich phases or oxides. The relatively bright morphological surface of the sample indicates the presence of a high iron content. Guano is known for its rich composition of minerals, including iron. Based on research conducted by (Sari, 2014) showed that the morphological state of guano samples that are not homogeneous and have a brighter color on the surface of the sample indicates the presence of iron content in the sample.

The morphological structure of the guano at 1250x magnification on the S7 code sample has a morphology that shows a variety of irregular, angular particles, likely representing a mixture of various materials or phases. The surface is not uniform, displaying dense areas and areas with larger, distinct particles. It denotes a composite or multi-phase material in which different components are present but not uniformly distributed. This is related to the results of XRD analysis where the S7 code sample has more compounds than the R3 code, causing the resulting image to be irregular.

The morphological differences between the two images correlate with the iron content detected by XRF. Iron, as a heavy metal, tends to form a dense and uniform structure, which is clearly seen in the second image with finer and more uniform particles. The morphological differences highlighted by the SEM images are in line with XRF's findings, where higher iron content leads to a more homogeneous and fine-grained structure, while lower iron content results in a more heterogeneous material composition.

Microstructure differences between R3 and S7 code guano samples may indicate variations in mineral composition and grain texture. Factors such as the environmental conditions in which the guano is obtained, the type of bird or animal that contribute to the guano, and the process of deposition and decomposition of guano can affect the observed microstructure. However, it should be remembered that in this sample it is not clear how the surface morphology is caused by too small magnification. Therefore, it can only indicate a surface that looks bright. A bright-looking surface can be an indication of magnetic mineral content.

These results demonstrate the importance of understanding the morphology and microstructure of guano in the context of specific applications or analyses, such as in environmental or agricultural research. Further analysis, perhaps using other electronic microscopy techniques or chemical analysis, can provide deeper insights into the composition and characteristics of relevant guanos.

CONCLUSION

Based on the results and discussions that have been described, it can be concluded that the magnetic susceptibility value of guano cave is higher than that of non-cave guano. This is due to the higher Fe content in guano caves. The magnetic susceptibility of cave guano is in the range of $278.0 \times 10^{-8} \text{ m}^3/\text{kg}$ to $832.7 \times 10^{-8} \text{ m}^3/\text{kg}$, while the non-cave guano sample is in the range of $23.7 \times 10^{-8} \text{ m}^3/\text{kg}$ to $51.1 \times 10^{-8} \text{ m}^3/\text{kg}$, the elemental composition of cave and non-cave guano samples has the same elements, namely, bromine (Br), chromium (Cr), copper (Cu), zinc (Zn), manganese (Mn), titanium (Ti), phosphorus (P), magnesium (Mg), aluminum (Al), potassium (K), iron (Fe), silicon (Si), calcium (Ca), and nickel (Ni), but in non-cave guano there is no element vanadium (V). XRD analysis on cave guano and non-cave guano samples showed the diversity of mineral phases. In cave guanos, mineral phases of SiO_2 , O_2V , MgO_3Si , P_4O_{10} , $\text{CaO}_{17}\text{P}_6$, FeKO_2 , NNaO_3 , and CCaO_3 were detected, while in non-cave guanos, there were additional mineral phases C_5CaO_5 , AlO_4P , $\text{Fe}_2\text{K}_2\text{O}_4$, MnO_2 , Fe_4O_5 , and FeO . And the study used Scanning Electron Microscopy (SEM) to characterize guano from cave and non-cave environments, with a focus on morphology. SEM images with 1250x magnification show the differences in microstructure between the R3 and S7 guano samples. Both samples feature a heterogeneous and coarse microstructure with many small particles that are aggregated and enclosed by non-magnetic elements.

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