RGNZ/MGPB

Magnetic characteristics and mineralogy of cave sediments from Solek Cave, West Sumatra: Implications for paleoenvironmental processes within the cave

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
DOI: 10.17794/rgn.2026.3.12

Original scientific paper

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Abstract

Cave sediments are essential as they preserve valuable archives of past environmental and climate conditions that physical and chemical measurements can reveal. In this study, we explore the magnetic characteristics of the cave sediments collected from Solek Cave, West Sumatra, Indonesia to understand environmental processes within the cave. We employed rock magnetic methods, including magnetic susceptibility, isothermal remanent magnetization (IRM), anhysteretic remanent magnetization (ARM), and Curie temperature measurements. Additionally, we used X-ray diffraction (XRD) and scanning electron microscopy (SEM) in order to analyze the magnetic mineralogy and morphology of the cave sediments. The results show a high concentration of magnetic minerals, specifically ferrimagnetic groups, indicated by high magnetic susceptibility ranging between 210.7 and 1301.2 × 10^{-8} m^3/kg, with a mean value of 602.7 × 10^{-8} m^3/kg. The calculated χ_{FD} (%) values ranged from 0.2 to 6.6, mostly less than 2%, indicating coarse-grained, multidomain ferrimagnetic minerals. Moreover, results from IRM, ARM and XRD show that the magnetic minerals are dominated by coarse-grained magnetite with a grain size of around 20 to 110 μm. Curie temperature measurements also exhibit various titanium proportions, forming a titanomagnetite phase. The morphology and chemical compositions of the magnetic minerals, determined by SEM and energy-dispersive X-ray spectroscopy (EDS), also support the previous analyses, showing that titanomagnetite is the dominant phase, characterized by coarse grain size and angular shape. The uniformity of the magnetic characteristics and mineralogy suggests a titanomagnetite mineral source likely driven by lithogenic processes such as erosion and fluvial events.

Keywords:
Cave sediments, West Sumatra, Magnetic characteristics, Titanomagnetite, Lithogenic

1. Introduction

Caves serve as valuable archives of environmental and climatic history due to unique conditions, which allow for the accumulation and preservation of sediments and other geological materials (e.g. **Sasowsky and Mylroie, 2004; White, 2007; González-Lemos et al., 2015; Onac et al., 2025**). Unlike other sedimentary deposits, such as lake, river and marine deposits, which are prone to a wide range of environmental disturbances, cave sediments are relatively protected from erosion, surface weathering and post-depositional processes. This makes them likely to preserve a more precise record (**Karkanas and Goldberg, 2017**). Cave sediments are typically deposited under stable conditions, controlled by a specific range of moisture and temperature. They are often associated with high accumulation rates driven by hydrological events. These deposits can also provide significant archeological information, including artifacts and remains of animals and humans, offering insight into past human activities (e.g. **Hunt et al., 2015; Riordan et al., 2021**).

The characteristics and preservation of environmental records in cave sediments are primarily governed by a variety of physicochemical changes (**El Abani et al., 2011; Epure et al., 2017; Addesso et al., 2022**). These changes are mainly influenced by processes involving water and wind, which result in the formation and alteration of elements and minerals from fragments of pre-existing rocks during sediment transport (**Haldar, 2020**). Magnetic minerals produced by these processes ultimately possess inherent magnetic properties that dictate

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Received: 12 May 2025. Accepted: 17 May 2025.
Available online: 14 May 2026

the past environmental processes. For example, the type of magnetic minerals found within a cave is related to reduction-oxidation (redox) conditions, and the various grain sizes of these magnetic minerals strongly indicate the mechanism of deposition, such as fine grains suggesting wind transport and coarse grains representing water transport (**Hatfield, 2014; Huang et al., 2025**).

Previous studies have explored the magnetic characteristics of the cave sediments to understand the presence and significance of magnetic minerals associated with cave deposits (e.g. **Ellwood et al., 1998; Sroubek et al., 2001; Jaqueto et al., 2016; Hajna et al., 2020; D'Arcangelo et al., 2021**). Iron (Fe), an ubiquitous element in rocks, soils and sediments, plays a crucial role in forming magnetic minerals. Therefore, analysis of magnetic minerals offer a promising avenue for understanding their origin and impact on paleoenvironmental processes within cave settings, as they serve as sensitive recorders of cave conditions and their surrounding environment (**Evans and Heller, 2003**). Furthermore, it has been suggested that the source of magnetic minerals in the cave sediments can be anthropogenic (human-influenced) and lithogenic (sourced from fragments of rock and mineral) (e.g. **Onac et al., 2015; Tiwow et al., 2025**). Rock magnetic methods are commonly employed to investigate the magnetic characteristics of the cave sediments because they are responsive to the presence of magnetic minerals, (e.g. **Onac et al., 2015; Rifai et al., 2018; Putra et al., 2019; Tiwow et al., 2025; Rifai et al., under review**). The techniques also offer the advantage of fast and non-destructive measurements.

Located in a critical equatorial region, Indonesian caves preserve high-resolution records of past climate and environmental shifts (**Ayliffe et al., 2013; Kimbrough et al., 2023; Krause et al., 2024**). Consequently, studying these caves is crucial for providing key insight into tropical climate dynamics and the Asian monsoon, which is vital for understanding global climate. The West Sumatra Province, which contains the karst systems of the Padang Highlands, offers numerous potential sites for conducting cave exploration and study. Some caves in West Sumatra have been studied previously to reconstruct paleoclimate (**Wurtzel et al., 2018**) as well as ecology, biology, and human history (e.g. **Wirkner and Hertler, 2019; Louys et al., 2022, 2024; Anderson et al., 2024**). Nevertheless, many caves in this region remain poorly understood and need to be further investigated.

In this study, we utilize rock magnetic methods to examine the magnetic characteristics of the cave sediments collected from Solek Cave, an unexplored cave in West Sumatra, Indonesia, to understand the source of magnetic minerals and their depositional mechanisms. The preserved magnetic minerals and their characteristics can indicate how they have been transported to the site. Building on a previous study by **Putra et al. (2019)** which only focused on one of magnetic parameters (i.e. magnetic susceptibility) and elemental composition of the cave sediments in Solek Cave, here we employ a comprehensive approach combining magnetic susceptibility, isothermal remanent magnetization (IRM), anhysteretic remanent magnetization (ARM), and Curie temperature measurements with additional analysis, namely X-ray diffraction (XRD) and scanning electron microscopy (SEM). This integrated approach allows us to constrain the magnetic characteristics, the types of magnetic mineralogy, and their morphology.

2. Methods

The typical cave sediments on the floor consisted of soil and were collected vertically in Solek Cave (0° 16′ S, 100° 43′ E). This cave is located within the carbonate host rocks and is part of the Barisan Mountains of West Sumatra (see **Figure 1**). The cave is developed within limestone strata of the Kuantan Formation (**Barber et al., 2005**), a constituent part of the Tapanuli Group within the West Sumatra Block. This formation, which dates to the Lower Carboniferous to Mid-Permian periods, is also known to include metasedimentary rocks in association with the primary limestone. Solek Cave is a dry cave with a floor that slopes slightly upward near the entrance. The fauna is dominated by bat colonies. The inner chambers contain minimal speleothem deposits. The cave's karst system and hydrological processes of Solek Cave have yet to be documented in previous studies. The cave is situated within a wet tropical rainforest ecosystem. This region experiences consistent high rainfall occurs each year, surpassing 150 mm monthly. While precipitation averages rise above 250 mm per month during the September to December peak, the lowest average monthly rainfall is seen in February (**Aldrian and Susanto, 2003**).

Samples were taken from the uniform brownish layers of soil clastic sediments, from the surface to bottom (when bedrock was reached) at 2 cm intervals and stored in Whirl-Pak™ bags. They were then refrigerated at 4°C until lyophilized for further analysis. All samples were subjected to mass-specific magnetic susceptibility measurement via an MS2 susceptibility meter (Bartington Instruments Ltd., Witney, UK). The device is fitted with a sample internal diameter of 35 mm and a MS2B dual-frequency sensor. During measurement, a magnetic field of 80 A/m was applied and the device allows the range of susceptibility to be measured from 1×10^{-6} to 9.999×10^{-6} in cgs or 1.26×10^{-5} to 1.026×10^{-1} in SI unit. Approximately 10 grams of the sample was carefully placed into a cylindrical plastic container with a 25.4 mm diameter and a 22 mm height. Magnetic susceptibility measurements were conducted using 1.0 sensitivity setting at 0.47 kHz for low frequency magnetic susceptibility (χ_{LF}) and at 4.7 kHz high frequency magnetic susceptibility (χ_{HF}), respectively. These two measurements allow for the estimation of the frequency-dependent magnetic sus-

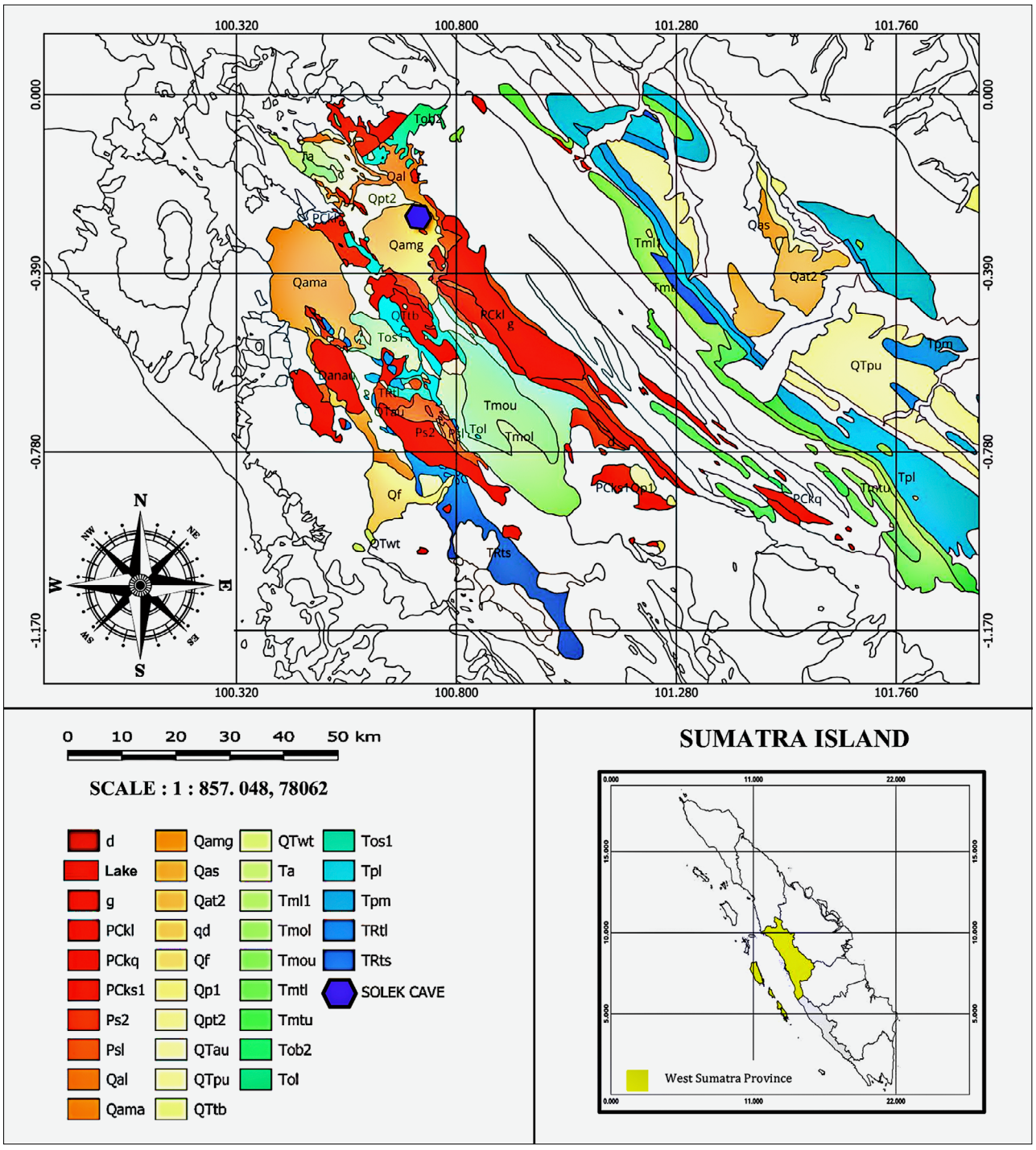

Figure 1. Geological map showing the study site Solek Cave in the West Sumatra Province (blue hexagon), which is located within the PCkl unit (limestone). The inset map shows Sumatra Island. The map legend details the following lithological units and features (abbreviation: lithology): d (intrusive: mafic), Danau (lake), g (intrusive: felsic), PCkl (limestone), PCkq and PCks1 (metasediment), Ps2 (intermediate polymict), Psl (clastic limestone), Qal, Qas, Qat2 (clastic alluvium), Qama, Qamg (intermediate polymict), qd (intrusive: intermediate), Qf (conglomerate), Qp1 (felsic granitoid), Qpt2, QTau, QTtb, QTwt (intermediate pyroclastic), QTpu (felsic pyroclastic), Ta (intermediate polymict), Tml1 (reef limestone), Tmol (sandstone), Tmou (fine claystone), Tmtl (marl), Tmtu (fine shale), Tob2 (conglomerate), Tol, TRtl (evaporite), Tos1 (fine shale), Tpl, Tpm (fine claystone), and TRts (slate).

ceptiblity, χ_{FD} (%), by calculating the ratio between χ_{LF} and χ_{HF} ($100\% \times (\chi_{LF} - \chi_{HF})/\chi_{LF}$ (**Oldfield et al., 1983**).

The selected samples were analyzed for IRM, ARM and Curie temperature measurements. IRM analysis was performed using an electromagnetic generator that incrementally increased the magnetic field at room temperature. IRM intensity was evaluated by a spinner magnetometer (Minispin magnetometer by Molspin Ltd.,

Newcastle Upon Tyne, UK), reaching a maximum intensity of 1000 mT, defined as saturated isothermal remanent magnetization (SIRM). An electromagnetic generator was also used for determining ARM intensity. Samples were exposed to a 2.5 mT direct current (DC) magnetic field and a 700 mT alternating magnetic field via Molspin AF Demagnetizer (Molspin Ltd., Newcastle Upon Tyne, UK). Selected samples were also extracted for obtaining magnetic minerals and then analyzed for Curie temperature using a Bartington MS2WFP Susceptibility Meter (Bartington Instrument Ltd., Witney, UK). This instrument was equipped with an MS2 Meter, MS2W Water Jacketed, MS2WF Furnace, MS2WFP Power Supply Unit, and a self-contained water coolant supply. The measurement involved heating the sample from a room temperature of 32°C to 750°C, and subsequently cooling it back to 32°C.

XRD type Phillips XD-610 instrument was utilized to identify magnetic mineralogy within extracted samples. The measurement employed CuKα target with a 0.154 nm wavelength (λ). The resulting data included diffraction angles, intensity values and distances between planes, in which these parameters can be related via the Bragg equation ($d = \lambda / 2 \sin \theta$). The magnetic mineral database was used for comparison to determine the types of magnetic minerals (**Cornell and Schwertmann, 2003**). The morphology of magnetic minerals extracted was examined via SEM (Phillips CM 12, PW 6030/10 instrument). Samples were imaged under secondary electron imaging (SEI) using an accelerating voltage of 20 kV and a working distance of 10 mm. Additionally, Energy-Dispersive X-Ray Spectroscopy (EDS) was applied to determine the element compositions.

3. Results and Discussion

3.1. Magnetic characteristics of cave sediment

Results of low magnetic susceptibility measurements (χ_{LF}), sediment samples in Solek Cave have values in the range between 210.7 to 1301.2 × 10^{-8} m^3/kg with a mean value of 602.7 × 10^{-8} m^3/kg (see **Figure 2**). All magnetic susceptibility peaks exhibit an irregular pattern through each depth, yet overall, the observed increasing values correspond to deeper layers. The range of values is in line with previous studies by **Putra et al.** (**2019**) at the order of hundred to thousand × 10^{-8} m^3/kg, which is suggested to have relatively high values, indicating the presence of ferrimagnetic mineral groups (**Tiwow et al., 2025**). The calculated χ_{FD} (%) values ranged from 0.2 to 6.6 with a mean of 1.3. However, most of χ_{FD} values lie in the range of less than 2% and are similar to results from **Putra et al.** (**2019**), except for 6.6%, which might be due to the sensitivity of the instrument during measurement. Values of less than 2% indicate the presence of coarse-grained, multidomain ferrimagnetic minerals (**Dearing et al., 1996; Putra et al., 2019**).

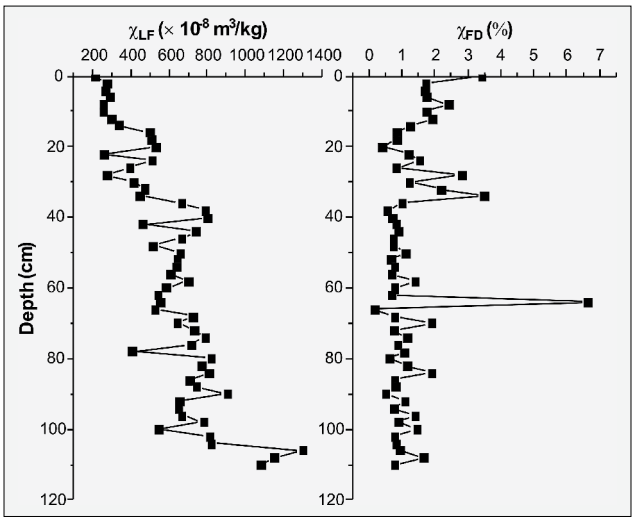

Figure 2. Magnetic susceptibility (left) and frequency dependent magnetic susceptiblity (right) of the cave sediments through each depth.

Figure 3 displays the measured IRM curves of selected samples. Samples undergo saturation at magnetic fields lower than 300 mT, which is indicative of a soft magnetite phase (e.g. **Bijaksana and Huliselan, 2010; Jin et al., 2016; Mariyanto et al., 2019**). Resulting ARM decay curves for selected samples are presented in **Figure 4**. The measured curves are used to approximate the grain size of magnetic minerals by observing MDF_{ARM} (Median Destructive Field) and comparing them with Lowrie-Fuller test graph (**Dunlop and Ozdemir, 1997**). Based on the observation, MDF_{ARM} values are in the range between 8 and 10 mT, where the magnetic minerals are suggested to have coarse grain sizes from around 20 to 110 μm.

Curie temperature curves displayed in **Figure 5** demonstrate the occurrence of iron-titanium oxides such as titanomagnetite with varying titanium proportions based on temperature drops. For both samples measured (GS_0-2 and GS_36-38), two temperature drops are uniquely observed in heating curves at around 300°C and 460°C, respectively, indicating the presence of two Curie temperatures. Instead, there is only one temperature drop in cooling curve observed at less than 500°C.

In heating experiments, magnetic susceptibility values become zero before achieving 580°C and subsequently decrease to negative numbers. Under this condition, magnetic minerals possibly transform from ferrimagnetic to paramagnetic. After switching to cooling experiments, magnetic minerals return to ferrimagnetic with increasing magnetic susceptibility values until maximum values are reached at less than 500°C. Finally, a decrease in magnetic susceptibility values is observed when going back to room temperature. It is noteworthy that the shape of both heating and cooling curves appear to be a bit similar, although cooling curves have only one temperature drop compared to heating curves and there is a higher cooling curve seen in the surface sample

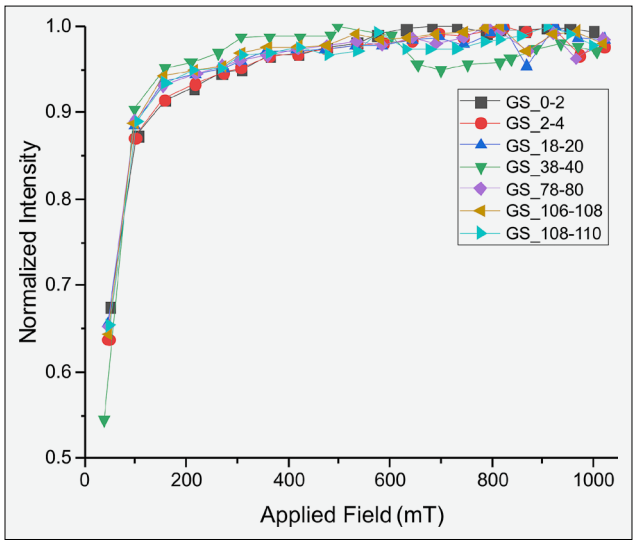

Figure 3: Isothermal remanent magnetization (IRM) curves of selected cave sediment samples.

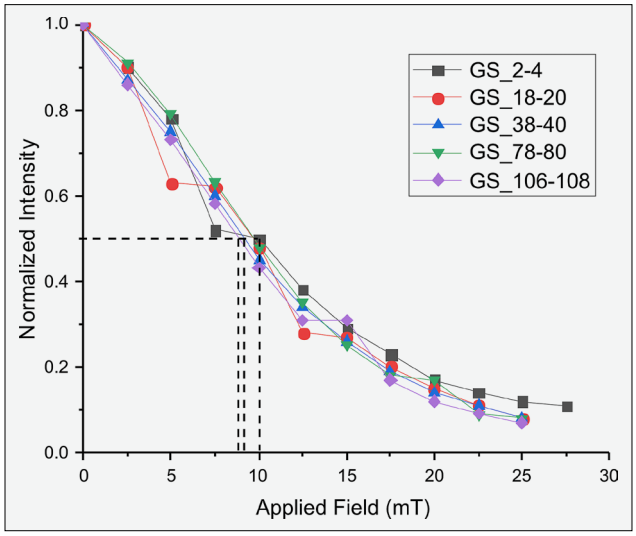

Figure 4. Anhysteretic remanent magnetization (IRM) curves of selected cave sediment samples. The dash lines indicate Median Destructive Field (MDF_{ARM}) at 0.5 corresponding to the applied field.

(GS_0-2) rather than its heating curve. The proportion of Ti content can be estimated using literature data by **Lattard et al. (2006)** and the polynomial expression for Curie temperatures of **Bleil and Peterson. (1982)**. Based on our matching with variations of the Curie temperature in the Fe-Ti-O system as a function of composition in literature data determined by **Brachfeld et al. (2024)**, magnetic minerals within sediments from Solek Cave may contain various titanomagnetite compositions between $Fe_{2.5}Ti_{0.5}O_4$ and $Fe_{2.95}Ti_{0.05}O_4$.

3.2. Magnetic mineralogy and morphology of the cave sediments

Peaks of the XRD diffractogram measured from extracted magnetic minerals indicate that the phase of

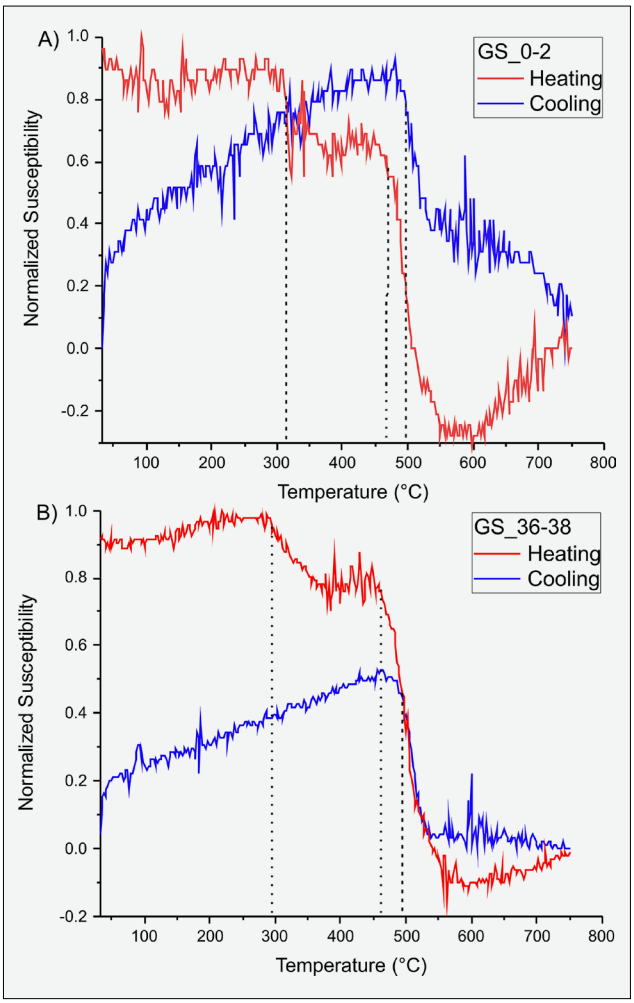

Figure 5. Representative Curie temperature curves based on temperature drops (dash lines) via temperature dependence of magnetic susceptibility (χ–T) measurements.

magnetite dominates within samples (see **Figure 6**). However, only a few peaks of hematite appear, which is suggested to have a small proportion in the cave sediments. Our XRD results thus reinforce IRM analysis, where magnetite is a major phase of magnetic minerals. **Figure 7a-d** shows the morphology of extracted magnetic minerals from selected samples via SEM images. Shapes of magnetic minerals are predominantly angular, with some exhibiting distinct of octahedral morphology. The sizes of the magnetic minerals range from around 20 to 100 μm or larger, implying that the magnetic minerals are predominantly coarse-grained and correspond to multidomain, which further supports ARM and χ_{FD} results.

Both angular and octahedral shapes characterize the presence of titanomagnetite fragments, as supported by previous studies (e.g. **Huliselan et al., 2010; Kirana et al., 2024**). EDS measurements were therefore made in order to quantify elements, including the presence of Fe and Ti within magnetic minerals. **Table 1** provides various element compositions based on selected grains of

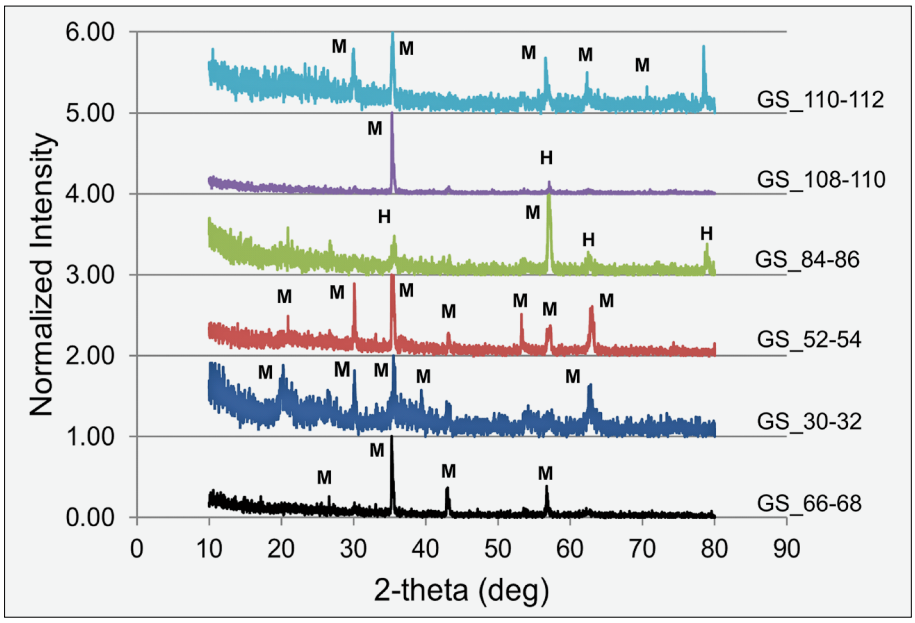

Figure 6. Diffractogram of XRD for representative extracted samples of cave sediment. Peaks indicate that magnetite (M) minerals dominate the diffractogram with minor hematite (H).

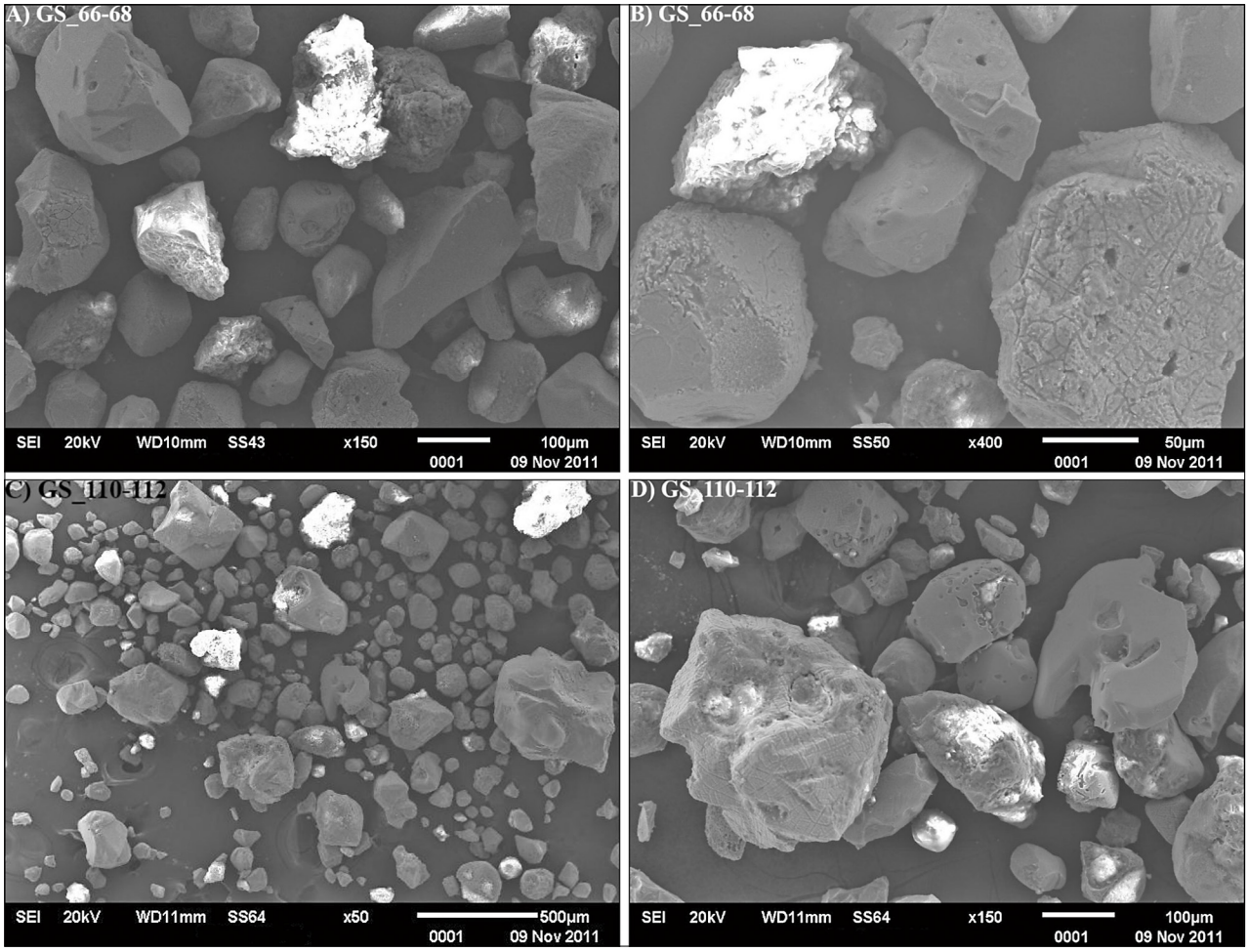

Figure 7. Representative SEM images of extracted samples showing the morphology of magnetic minerals in angular shape.

magnetic mineral from **Figure 7b** and **7d**. Fe is identified as the primary element composing magnetic minerals, followed by some elements such as Ti, Al, and Si. The presence of C might be due to organic abundance associated with sediments. Other elements such as P, Mg and K are considered as minor elements since these ele-

Table 1. Energy-Dispersive X-Ray Spectroscopy (EDS) analytical data (mass%) on selected magnetic mineral grains.

Sampel ID	Element Composition (%)										
	C	O	Al	Si	Mg	P	K	Ca	Ti	Fe	Total
GS_66-68 grain 1	4.65	35.55	5.01	6.45	-	3.46	0.46	11.66	1.68	31.06	99.98
GS_66-68 grain 2	2.66	18.54	3.33	2.02	-	0.28	0.06	0.66	15.44	57.01	100
GS_66-68 grain 3	8.76	28.23	8.65	8.38	-	5.99	5.07	1.27	2.39	31.25	99.99
GS_110-112 grain 1	6.09	46.08	12.64	17.49	0.40	-	0.17	0.94	0.70	15.49	100
GS_110-112 grain 2	3.17	29.11	3.26	1.91	1.15	-	0.08	0.24	6.44	54.65	100.01
GS_110-112 grain 3	3.34	21.59	2.53	2.16	0.41	-	-	0.12	20.67	49.17	99.99

ments either have a small proportion or are undetectable within magnetic mineral grains. Magnetic mineral grains also contain Ca, which is mostly in low concentrations. Since Fe- and Ti- bearing magnetic minerals are present in sediments, we assume that titanomagnetite is the dominant phase, which is also confirmed by the results of the Curie temperature analysis.

3.3. Source of magnetic mineral and its implications for paleoenvironmental processes

Several studies have investigated the magnetic characteristics of clastic sediment in various caves around the world using rock magnetic methods. Some have suggested that the peak of magnetic susceptibility can be related to climate record (e.g. **Sroubek et al., 2001; Ellwood et al., 2004; Benedetti et al., 2019; D'Arcangelo et al., 2021**), while others found that magnetic susceptibility enhancement can be controlled by anthropogenic influence (e.g. **Onac et al., 2015; Rifai et al., 2018; Paar et al., 2025**). In this study, our sampling point in Solek Cave is different compared to a previous study by **Putra et al.** (**2019**), but still in the same cave. Meanwhile, the authors have reported that the magnetic susceptibility signal of sediments in Solek Cave seems to be irregular but in the range of high values, similar to our results. This pattern was also recently confirmed by **Rifai et al.** (**under review**) in studying magnetic characteristics of guano deposits associated with clay from Rantai Cave in West Sumatra with a combination of radiocarbon and organic matter measurements. They suggest that variation in magnetic susceptibility values can be due to detrital influx by fluvial response, which in turn to causes variability in the accumulation rate of magnetic minerals and results in mixing of guano and sediment layers. Radiocarbon dating and organic analysis might be necessary in the future studies to identify potential mixing processes in the cave sediments from Solek Cave.

Our results indicate that titanomagnetite is the dominant phase and has a strong influence on the magnetic characteristics of sediments. Titanomagnetite minerals are ubiquitous in different geological settings, including igneous and metamorphic rocks as well as sedimentary environments. The occurrence of titanomagnetite often serves as an indicator of changes in environmental conditions, implying complex transportation and weathering processes. Moreover, uniformity of magnetic characteristics and mineralogy, namely dominant type, coarse grain size and morphology of magnetic minerals, possibly indicates a common source for titanomagnetite.

We did not find any spherule forms in the morphology of magnetic minerals in **Figure 7**, which commonly originate from anthropogenic sources (**Jordanova et al., 2004; Kirana et al., 2024; Liang and Wang, 2024**). Instead, most of the angular shapes are distinguishable, suggesting that the magnetic minerals in Solek Cave are unlikely to be linked to human activity. If magnetic characteristics are derived from different climate processes, distinctive features in the sediment profile, indicating a heterogeneous source, would be expected. Another recent study by **Onac et al.** (**2025**) explored the presence of Ti in cave sediments and suggested that Ti is an indicator of the lithogenic component that strongly contributes to external environmental conditions, such as past erosional and weathering processes. Ti is also considered to be resistant in its host minerals (e.g. titanomagnetite), which does not readily dissolve or change in chemical processes under normal conditions (**Mbanga et al., 2022**).

The consistent and high concentration of magnetic minerals, particularly titanomagnetite, throughout the sediment profile suggests significant and dynamic depositional processes at play in Solek Cave, likely driven by lithogenic processes such as erosion and fluvial events. This interpretation is supported by variation and erratic pattern of high magnetic susceptibility shown in **Figure 2**, indicating the fluctuating depositional rate of magnetic minerals, which is strongly related to high detrital influx (**Dearing, 1999**). It is also noteworthy that deeper (old) layers exhibit higher susceptibility, implying more intense fluvial transport processes carrying magnetic minerals rather than shallow (younger) layers.

Meanwhile, there is a possibility of magnetic mineral diagenesis in the sediments, which can alter detrital magnetic minerals due to reduction-oxidation (redox) reactions (**Roberts, 2015**). Such processes can transform magnetite into minerals like hematite and goethite

in oxic conditions, or greigite and pyrite in anoxic conditions. Nevertheless, based on the strong detrital magnetic signal, we assume that diagenesis processes have a minor contribution to the magnetic properties of the Solek Cave sediments. To assess the paleoenvironmental implications, future research should aim to obtain high-resolution of geochemical or sedimentological records from the cave. In particular, correlation between magnetic susceptibility signals with regional climate proxies is recommended to reveal climatic controls due to detrital influx.

4. Conclusions

The magnetic susceptibility of the cave sediments from Solek Cave in West Sumatra reveals a high concentration of magnetic minerals, specifically ferrimagnetic groups, with values ranging between 210.7 and 1301.2 × 10^{-8} m^3/kg, with a mean value of 602.7 × 10^{-8} m^3/kg. Further analysis using calculated χ_{FD} (%) values, IRM and ARM curves as well as XRD results, indicates the presence of coarse-grained multidomain magnetite mineral with a size from around 20 to 110 μm. Curie temperature curves also confirm various titanium proportions forming the titanomagnetite phase. Mineralogy and morphology investigation then supports previous methods used where titanomagnetite is the dominant phase of magnetic mineral type, characterized by coarse grain size and angular shape. Uniformity of magnetic characteristics and mineralogy suggests a titanomagnetite mineral source, which is likely driven by lithogenic processes, such as erosion and fluvial events.

Acknowledgement

The authors thank James Cook University's College of Science, Technology and Engineering, National Geographic Society's Scientific Research 8845-10, and Australian Institute of Nuclear Science and Engineering award (ALNGRA11033) to CMW for supporting fieldwork and Research Grants from Hibah Bersaing DIKTI, DIPA Universitas Negeri Padang numbers 1790/UN35.2/PG/2017 and RKAI − PKPTLN No. 1927/UN35.15/LT/2025 to HR for the analysis of magnetic characteristics and mineralogy in this research. The authors also thank Mila Novrilita and Tiwi Olintika for their valuable help during fieldwork.

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SAŽETAK

Magnetna svojstva i mineralogija špiljskih sedimenata iz špilje Solek, Zapadna Sumatra: implikacije za paleoekološke procese unutar špilje

Špiljski su sedimenti ključni jer čuvaju vrijedne arhive prošlih okolišnih i klimatskih uvjeta koje fizička i kemijska mjerenja mogu otkriti. U ovoj studiji istražuju se magnetne karakteristike špiljskih sedimenata prikupljenih iz špilje Solek, Zapadna Sumatra, Indonezija, kako bi se razumjeli okolišni procesi unutar špilje. Korištene su metode magnetne analize stijena uključujući magnetnu susceptibilnost, izotermnu remanentnu magnetizaciju (IRM), anhisterezičnu remanentnu magnetizaciju (ARM) i mjerenja Curiejeve temperature. Osim toga, korištena je rendgenska difrakcija (XRD) i skenirajuća elektronska mikroskopija (SEM) kako bi se analizirala magnetna mineralogija i morfologija špiljskih sedimenata. Rezultati pokazuju visoku koncentraciju magnetnih minerala, posebno ferimagnetnih skupina, što je naznačeno visokom magnetnom susceptibilnošću u rasponu između 210,7 i 1301,2 × 10^{-6} m^3/kg, sa srednjom vrijednošću od 602,7 × 10^{-6} m^3/kg. Izračunane vrijednosti χFD (%) kretale su se od 0,2 do 6,6, uglavnom manje od 2 %, što upućuje na grubozrnate, višedomenske ferimagnetne minerale. Štoviše, rezultati IRM-a, ARM-a i XRD-a pokazuju da među magnetnim mineralima dominira grubozrnati magnetit s veličinom zrna od oko 20 do 110 μm. Mjerenja Curiejeve temperature također pokazuju različite udjele titana tvoreći titanomagnetitnu fazu. Morfologija i kemijski sastav magnetnih minerala, određeni SEM-om i energetski disperzivnom rendgenskom spektroskopijom (EDS-om), također podržavaju prethodne analize pokazujući da je titanomagnetit dominantna faza, karakterizirana grubom veličinom zrna i kutnim oblikom. Ujednačenost magnetnih karakteristika i mineralogije sugerira da je izvor titanomagnetitnoga minerala vjerojatno potaknut litogenim procesima poput erozije i fluvijalnih događaja.

Ključne riječi:
špiljski sedimenti, Zapadna Sumatra, magnetna svojstva, titanomagnetit, litogeni

Author's contribution

Hamdi Rifai (PhD, Associate Professor): conceptualization, sampling, funding, acquisition, supervision, interpretation, formal analysis, visualization, writing - original draft, writing - review editing. **Rizaldi Putra** (M.Sc): conceptualization, acquisition, investigation, interpretation, formal analysis, visualization, writing - original draft, writing - review editing. **Wilda Febi Rahmadhani** (B.Sc): acquisition, investigation. **Nilam Sari** (M.Sc): acquisition, investigation. **Dessupri Niarti** (B.Sc): acquisition, investigation. **Wardina Nasution** (B.Sc): acquisition, investigation, visualization. **Erni Erni** (M.Sc): sampling, investigation, supervision, interpretation, resources, writing - review editing. **Christopher M. Wurster** (PhD): sampling, funding, acquisition, supervision, writing - review editing.
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