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Mineralogical analysis of plutonic and volcanic rocks at selected slope sections of the Kuala Lumpur-Karak Highway

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Abstract
The Kuala Lumpur-Karak Highway (KL-KH) is a key route connecting Kuala Lumpur to the East Coast states of Peninsular Malaysia. It passes through three distinct geological formations: the Kuala Lumpur Granite, Genting Sempah Complex, and Bentong Raub Suture Zone. These formations feature unique rock mineral compositions and microstructures that influence the strength and behavior of rock masses. This study used X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) to analyze the mineralogical properties of plutonic and volcanic rock samples from the highway. The plutonic sample from KM29 (GKM29) consists of quartz, muscovite, and albite, while the volcanic sample from KM93 (LKM93) is rhyolite, containing quartz, albite, muscovite, and biotite. While both samples share similar minerals, they differ in texture, mineral proportions, and carbon content. The GKM29 sample has a more granular texture, while the LKM93 sample is finer. These differences in mineral composition and texture affect the mechanical properties of the rocks, including strength and durability, which are crucial for slope stability. Understanding these variations is essential for assessing slope stability and potential geological hazards along the highway. This study emphasizes the importance of early geological assessments for effective slope management and road safety, enabling better planning and maintenance strategies.

Keywords:
Granite;
Petrography;
Rhyolite;
SEM;
X-Ray Diffraction;

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INTRODUCTION

Peninsular Malaysia is characterized by three primary longitudinal belts: Western, Central, and Eastern, each distinguished by its unique stratigraphy, geological history, and magmatic characteristics [1]. The long history of tectonic and volcanic activity has resulted in the formation of diverse rock types with distinct mineral compositions and microtextures, which influence their strength and kinematic behavior. The Kuala Lumpur-Karak Highway (KL-KH) traverses these geological belts, but there remains a significant gap in research concerning the mineralogy and petrography of the plutonic and volcanic rocks found along this crucial transport route. Based on Table 1, previous studies on the KL-KH have predominantly focused on geological history and slope stability analysis, while detailed mineralogical investigations of the highway's rock formations remain limited. This lack of in-depth mineralogical research has significant implications for slope stability analysis, as the mineral composition, texture, and microstructure of the rocks directly affect their mechanical properties, including strength, weathering behavior, and susceptibility to slope failure.

Table 1. Previous studies associated with KL-KH

No	Year	Research Scope and Objective			References
		Historical of Geological Formation	Petrology & Mineralogy Analysis	Others	
1	1983	/			[6]
2	1994			Kinematic analysis	[7]
3	2000	/			[8]
4	2005		/		[1]
5	2009			Microcrack pattern	[9]
6	2010			Slope stability study using GIS	[10]
7	2012	/			[11]
8	2015	/			[12]
9	2019			Slope stability using kinematic and LEM	[13]
10	2021			Soil shear strength	[14]
11	2022			Rock mass quantification	[15]
12	2023		/		[16]

Without a comprehensive understanding of these properties, slope stability models may fail to account for key factors, potentially leading to inadequate mitigation measures and an increased risk of slope failures. This study aims to address this gap by conducting a thorough mineralogical and petrographic analysis of plutonic and volcanic rocks from selected outcrops along the KL-KH, specifically at KM29 and KM93, to better understand their influence on slope stability.

Globally, numerous studies have underscored the critical role of mineral composition in determining the mechanical properties and stability of rock slopes. For instance, research on volcanic rocks in the Andes and Cascade Mountains has demonstrated that variations in mineral content, such as the presence of biotite, feldspar, and quartz, significantly influence the rock's weathering resistance, strength, and failure mechanisms under stress conditions [2]. Similarly, studies in the Himalayan region have highlighted how the mineralogical composition of granite and rhyolite impacts the rock's mechanical behavior, particularly under tectonic and weathering pressures. Locally, while some studies [1][3] have focused on the geological history and general petrography of rocks in the KL-KH region, including the Genting Sempah Complex and Bentong Raub Suture Zone, there remains a paucity of research that explicitly compares the mineralogical properties of plutonic and volcanic rocks and their influence on slope stability. Existing studies have primarily concentrated on broader geological features without delving into the specific mineralogical aspects that govern rock strength and behavior, particularly in relation to slope stability in this context. These studies suggest that a more detailed, comparative analysis of plutonic and volcanic rocks, with a focus on their mineral content, texture, and microstructure, is essential to accurately assess their contribution to slope instability. Such research is crucial for improving the precision of slope stability models and informing better mitigation strategies along the KL-KH.

The primary gap in the existing literature on the KL-KH lies in the lack of detailed mineralogical and petrographic analysis of the plutonic and volcanic rocks found along the highway. While some geological and geochemical studies have been conducted, there has been little to no comparative research on how variations in the mineral composition of these rocks affect their mechanical properties, strength, and slope stability. The absence of such detailed studies limits the ability to make accurate predictions about slope instability and increases the risk of ineffective mitigation efforts. Given that rock mass strength and behavior are heavily influenced by mineralogical factors, a better understanding of these properties is critical to improving slope stability assessments and risk management. The failure to address this gap may result in unsafe conditions and hinder the development of appropriate engineering solutions for slope stabilization. This study seeks to address this gap by conducting a comprehensive analysis of the mineralogy and petrography of both plutonic and volcanic rocks from outcrops at KM29 and KM93 of the KL-KH. The research aims to establish correlations between mineral assemblage, rock strength, and slope instability, thereby providing a more accurate basis for slope stability analysis and enhancing the effectiveness of mitigation strategies.

This research is novel in several key aspects. First, it focuses on the KL-KH, a critical transportation corridor that traverses multiple geological belts, each with distinct mineralogical characteristics. Although previous studies have examined the geological history and slope stability of the KL-KH, this study uniquely addresses the mineralogical and petrographic aspects of the plutonic and volcanic rocks along the highway, offering new insights into how these properties affect slope behavior. Second, the study employs advanced analytical techniques, including X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM), to conduct a high-resolution mineralogical analysis of rock samples from outcrops at KM29 and KM93. These methods enable precise identification of mineral compositions, textures, and microstructures, providing detailed data on rock mass strength and stability [4][5].

The expected outcomes of this research will contribute to the academic understanding of the mineralogical properties of the rocks in the KL-KH region and have practical applications in slope stability analysis. The results will inform the development of more reliable and location-specific slope stability models, aiding in creating more effective mitigation measures and ultimately improving road safety and infrastructure resilience. This research thus represents an important step forward in addressing the challenges of slope management along one of Malaysia's most vital highways.

Geological And Stratigraphical Settings

The Kuala Lumpur-Karak Highway is the main highway connecting Kuala Lumpur to the East Coast states in Peninsular Malaysia, spanning from Gombak, Selangor, to Lanchang, Pahang. It traverses flatland and mountainous terrain across three geological formations: the Kuala Lumpur Granite, Genting Sempah complex, and Bentong Raub Suture zone. These formations lie within the Main Range of Peninsular Malaysia, also known as Western Belt Granites, as shown in Figure 1.

The Main Range Granite formed in the Permian to Triassic age, and each formation in the area has a distinctive granite unit. Unit 1 consists of megacrystic biotite granite, Unit 2 comprises megacrystic muscovite-biotite granite, Unit 4 is predominantly microgranite, aplite, and pegmatite, and Unit 3 is equigranularity tourmaline-muscovite granite [17].

METHOD

Rock Sample Collection and Field Observation

The fresh rock samples were collected from two exposed outcrops at KM29 and KM93 of the KL-KH between longitude and latitude 3°30'38.8"N / 102°07'36.0"E and 3°18'54.8"N / 101°44'13.6"E, respectively.

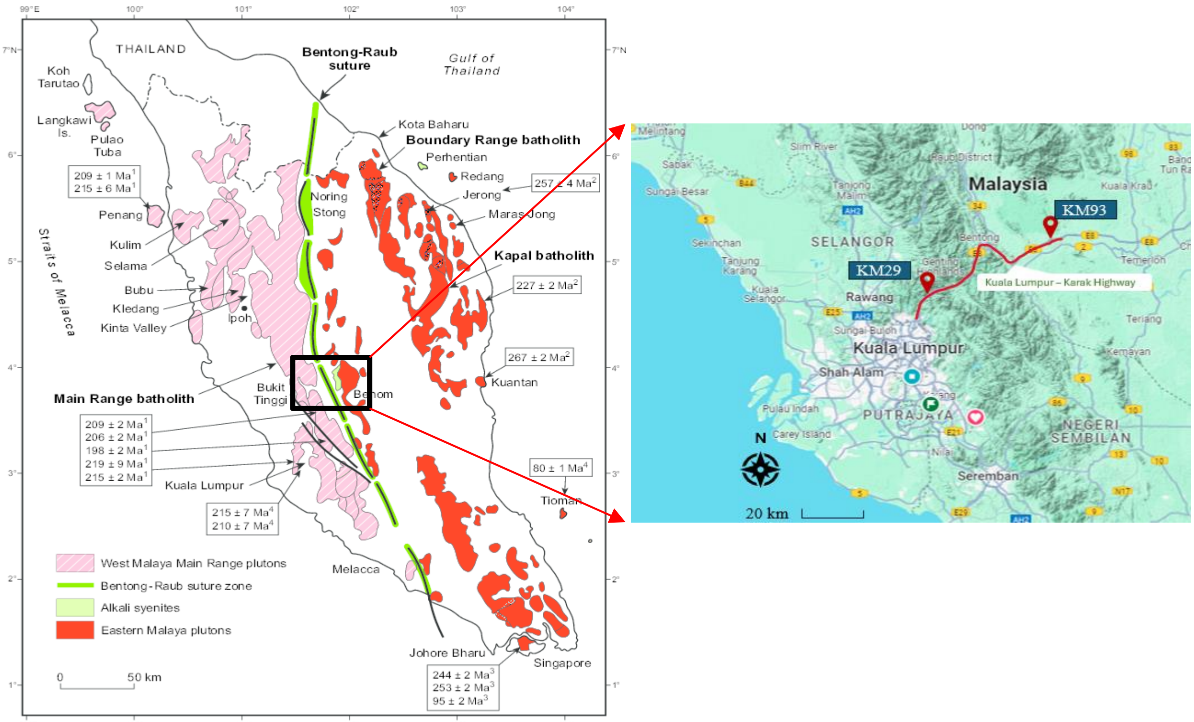

Figure 1. Division of granites in Peninsular Malaysia and location of study area. Modified from [17]

The rock samples were obtained using a geological hammer. The sample extracted at KM29 was designated GKM29, and that from KM93 was LKM93 (see Figure 2).

The field investigation and observations determined the characteristics of rock materials. GKM29 has coarse to medium grain texture, with yellowish to whitish grey. LKM93 is fine-grained and yellowish to whitish grey. The similar yellowish to whitish-grey color of both samples suggests an identical mineral composition and any color variations could be due to the differences in alteration or weathering processes.

The weathering grades at both slopes are classified as grade III and IV, based on their appearances. Figure 3 shows the jaw crusher and tungsten carbide mill machine employed in preparing the solid and powdered samples.

X-Ray Diffraction (XRD) Sample Preparation

This study quantified the mineral composition of the rock samples using the Rigaku ZSX Primus IV machine to conduct the XRD and calculated the diffraction angle beamed by the X-ray transmission. The rock sample was micronized into a homogenous size and compressed into a powder pellet, as shown in Figure 4.


(a) (b)

Figure 2. Rock sample (a) GKM29 - granite (b) LKM93 – rhyolite

(a) (b)

Figure 3. Rock sample preparation using: (a) jaw crusher (b) tungsten carbide machine


(a) (b)

Figure 4. Powdered sample for XRD analysis (a) sample GKM29 (b) sample LKM93

Scanning Electron Microscope (SEM) Preparation

Figure 5 shows the rock sample mounted on the SEM holder for analysis. The mineral composition was examined using the Carl Zeiss Gemini SEM 500 Model, a high-resolution scanning electron microscope equipped with a field emission gun (FEG) for enhanced resolution. This system also features an Oxford Instruments energy-dispersive X-ray spectroscopy (EDS) detector, which allows for precise identification and quantification of the sample's elemental composition. The spectra obtained were processed using the Smart SEM 5.0 software, ensuring accurate data interpretation. The analysis was conducted at 500 times magnification, providing a detailed view of the rock's microstructures and elemental distribution, contributing to a deeper understanding of its mineralogical characteristics.

RESULTS AND DISCUSSIONS

XRD Analysis

The X-ray diffraction (XRD) analysis of the GKM29 and LKM93 samples revealed that both rocks are predominantly composed of minerals typical of felsic igneous rocks, such as granite and rhyolite, characterized by their rich content of silicon (Si), aluminum (Al), sodium (Na), and potassium (K). Figure 6 shows the presence of quartz, feldspar, and mica, which are common minerals in both granite and rhyolite, in line with previous studies on similar rock types [18][19].

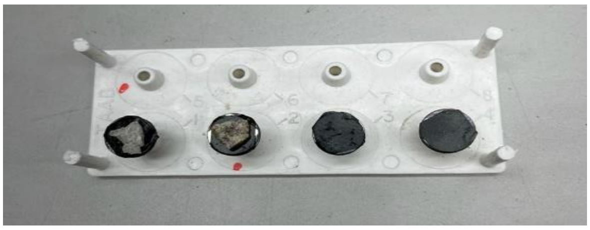

Figure 5. Sample mounts (both chip and powder) on the holder

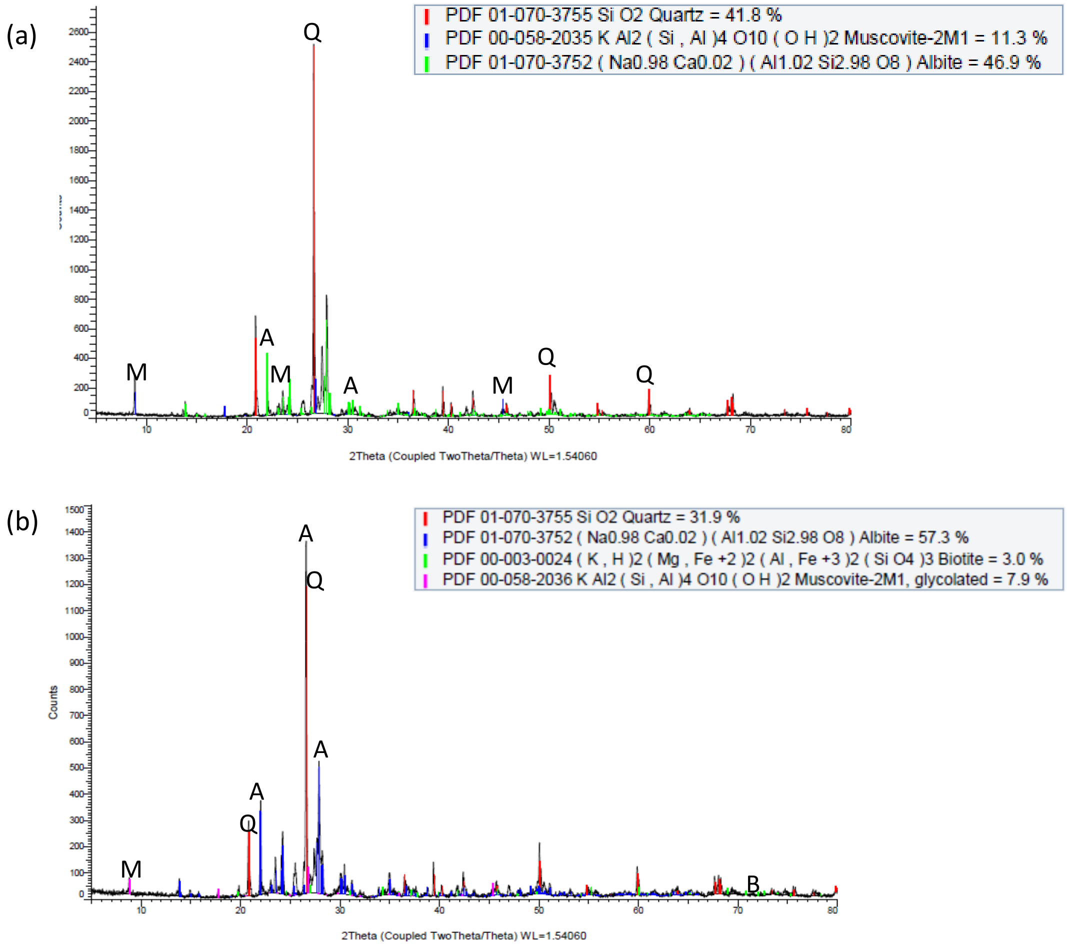

Figure 6. Powder X-ray diffraction patterns of samples (a) GKM29 (b) LKM93 Abbreviations: Q, quartz; M, muscovite; A, albite; B, biotite

The GKM29 sample exhibited a higher quartz concentration (more than 40%) compared to the LKM93 sample, which contained 31.9% quartz. This suggests that GKM29 may possess enhanced mechanical properties due to the higher proportion of quartz, a mineral known for its durability and resistance to weathering, as evidenced by Ghasemi et al. [20] and He et al. [21].

Both samples contained feldspar, with albite being the dominant type. The GKM29 sample had a feldspar concentration of 46.9%, while LKM93 contained 57.3%, reflecting the feldspar-rich nature of both rocks. Micas, including muscovite and biotite, were present in lower amounts, with the GKM29 sample containing 11% muscovite and the LKM93 sample containing 7.9%. Biotite was found in trace amounts in LKM93 (3%). Though minor in comparison to quartz and feldspar, micas influence the overall weathering behavior and mechanical properties of the rock based on Table 2.

SEM Analysis

The scanning electron microscopy (SEM) analysis, coupled with Energy Dispersive Spectroscopy (EDS) mapping, provided further insights into the elemental composition of both samples at the micro-scale. Both GKM29 and LKM93 results were shown in Table 3 where high concentrations of silicon (Si) and oxygen (O), indicative of silicate minerals such as quartz and feldspar.

Table 2. XRD contrast between granite and rhyolite

Minerals	GKM29 (%)	LKM93 (%)
Albite (Feldspar)	46.9	57.3
Quartz	41.8	31.9
Muscovite (Mica)	11.3	7.9
Biotite	0	3

Table 3. EDS analysis of element presence in sample

Element	GKM29 (%)	LKM93 (%)
Si	36.81	13.98
O	46.89	54.11
C	16.3	31.91

The GKM29 sample, which exhibited a higher quartz content, also displayed a higher proportion of silicon, aligning with the XRD analysis, as shown in Figure 7.

A significant difference between the two samples was the carbon content, with LKM93 containing 31.91% carbon and GKM29 containing 16.3%. The higher carbon content in LKM93 can be attributed to the volatile-rich nature of rhyolitic magma, which traps more carbon during rapid cooling. This observation is consistent with previous studies by Yu et al. [24], which indicated that rhyolitic rocks often have higher concentrations of volatiles due to rapid cooling. In contrast, the slower cooling of granitic magma in GKM29 allows for the removal of carbon through mineral formation, as discussed by Large et al. [25].

The mineralogical differences between GKM29 and LKM93 have significant implications for their weathering resistance and mechanical properties. The higher quartz content in GKM29 suggests that this granite sample is more resistant to weathering. Quartz is known for its durability and resistance to environmental degradation, which likely enhances the rock's mechanical properties and makes it more suitable for applications that require stability over time. On the other hand, the higher carbon content and lower quartz concentration in LKM93 suggest that this rhyolitic sample may be more prone to weathering and mechanical degradation. The higher volatile content in rhyolitic magma contributes to the greater carbon concentration in LKM93, which could influence its mechanical strength and response to environmental conditions. These differences highlight the contrasting behaviors of granite and rhyolite under varying cooling rates, with implications for their use in geotechnical and construction applications, where rock stability and durability are key considerations.

In conclusion, the combined results from the XRD and SEM analyses emphasize the significant mineralogical distinctions between granite and rhyolite, with important consequences for their weathering resistance and mechanical behavior. GKM29, with its higher quartz content, is likely to be more durable and resistant to weathering compared to LKM93, which has a higher carbon content and may exhibit lower mechanical strength. These findings contribute to a better understanding of the geochemical processes that influence rock properties, with potential applications in construction, mining, and environmental management. Further studies could focus on quantifying the mechanical properties of these rocks in relation to their mineral content and weathering characteristics, providing additional insights for practical applications.

CONCLUSION

The GKM29 plutonic (granite) sample had a course to medium texture, and LKM93 had a fine-grained texture. GKM29 comprised quartz, muscovite, and albite, while LKM93 consisted of quartz, albite, muscovite, and biotite. Feldspar was dominant compared to quartz in both samples. Quartz mineral in GKM29 sample accounted for more than 40% compared to LKM93, 31.9%. Even though the mineral content of both samples was similar, they had different textures and percentages of quartz, feldspar and carbon content. The different textures and percentage of minerals contribute to the stability of the slope. It can be used as an early indicator for slope study.

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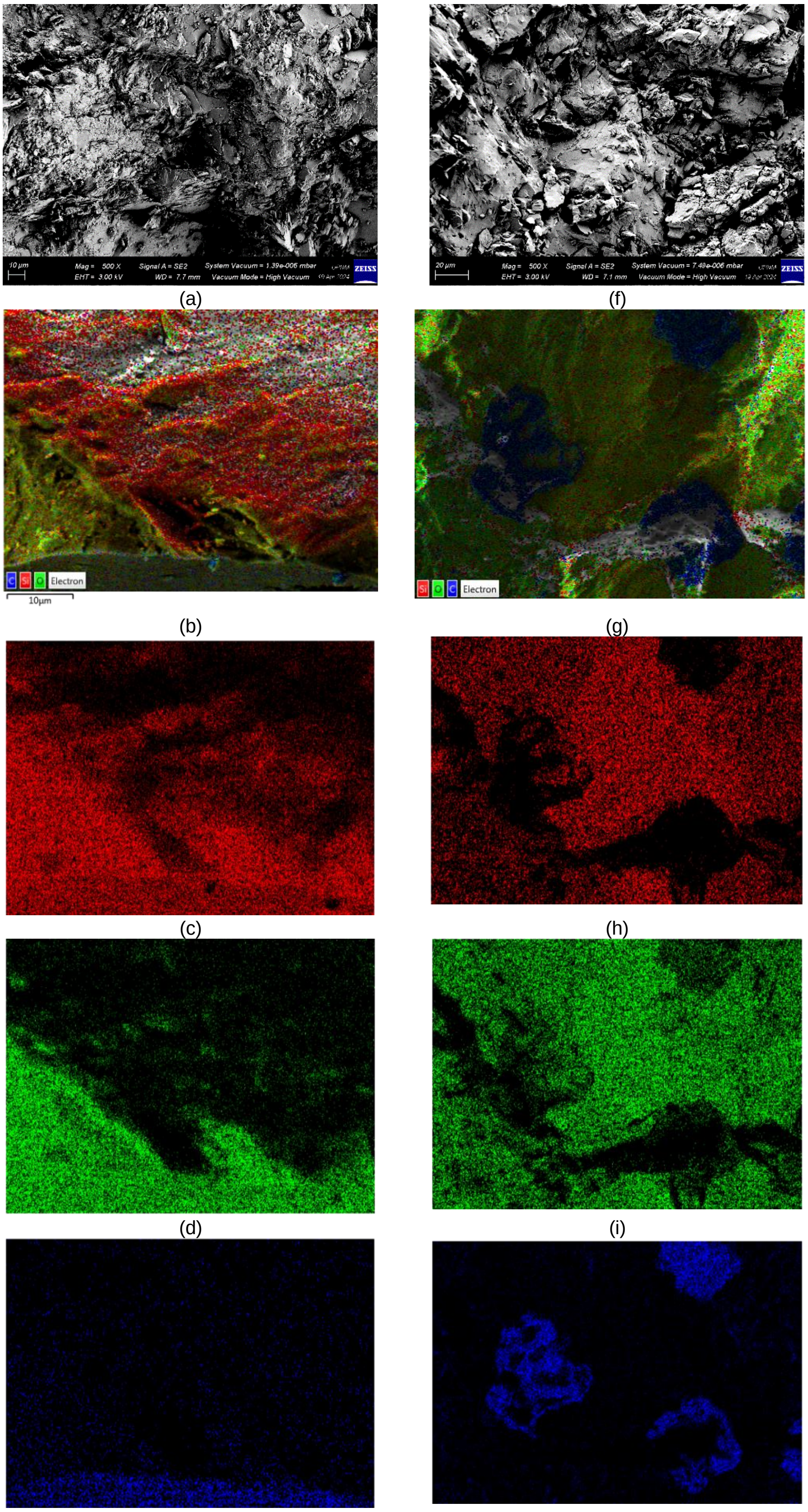

(a) (f)

(b) (g)

(c) (h)

(d) (i)

(e) (j)

Figure 7. SEM and SEM-EDS analysis. Maps of layered, Si Kα1, O Kα1, C Kα1 (a-e) GKM29 (f-j) LKM93

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