Original Article

e-ISSN: 2581-0545 - https://journal.itera.ac.id/index.php/jsat/

Received 22nd November 2025
Accepted 22nd May 2025
Published 04th August 2025

Open Access

DOI: 10.35472/jsat.v9i1.2026

Mineralogical Characteristics and Critical Stress Variation in Rock Samples from Bukit Kunyit, Bandar Lampung

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Abstract: Mineralogy plays a crucial role in understanding the processes of rock formation and their physical properties, including critical stress. Critical stress values can be estimated using unconfined compressive strength (UCS) measurements, which are influenced by the modulus values of the minerals present. This study investigates the mineralogical characteristics of rock samples from Bukit Kunyit in Bandar Lampung City, Lampung, employing X-ray diffraction (XRD) and petrographic analysis. Macroscopic observations revealed two visually distinct rock samples: one characterized by a bright color (Sample 1) and the other by a darker hue (Sample 2). Despite these apparent color differences, XRD analysis confirmed that both samples share the same mineral composition, comprised of Anorthoclase, Cristobalite, Tridymite, and Muscovite, which indicates a felsic (silica-rich) nature. Notable differences were observed in the crystallographic forms of Muscovite, as well as the Quartz content, with Sample 2 containing a higher concentration of Quartz. These mineralogical variations correlate with the differences in critical stress observed, as Sample 1 exhibited a lower critical stress of 20.98 MPa compared to Sample 2's 35.05 MPa.

Keywords: rock mineralogy, X-ray diffraction, petrography, Bukit Kunyit, critical stress.

Introduction

Mineralogy is crucial in understanding rock formation processes and their physical properties [1], [2]. One of the most critical physical properties is vital stress, which denotes the maximum stress a rock can withstand before failure. This parameter represents rock's strength, directly related to rock mechanics, and is widely used in applications such as geotechnics [3], landslide studies [4], mining [5], and reservoir analysis [6]. Understanding rock strength can aid in evaluating reservoir formations, predicting layer stability, and designing safer and more efficient drilling methods. Thus, understanding the relationship between mineralogy and rock physical properties becomes essential in assessing formation strength and stability across various situations and conditions [7].

The connection between mineralogy and rock strength is highly influenced by mineralogical composition. Variations in mineral composition can significantly impact a rock's strength, stiffness, and elastic modulus. Each mineral exhibits distinct mechanical properties, with certain minerals, such as quartz and carbonates, increasing the overall brittleness of the rock [5], [8].

Although numerous studies have explored the relationship between mineralogy and rock elasticity, there still needs to be more understanding of how minor variations in mineral composition and crystallographic structure can affect rock properties [9]. Rocks with similar mineral types can display different mechanical properties, as illustrated by the role of muscovite in reducing a rock's critical stress. Further research is therefore needed to investigate the factors influencing rock elasticity and critical stress [10], [11].

This study explores the mineralogical characteristics of two rock samples collected from Bukit Kunyit, Bandar Lampung City, Lampung. Mineral characterization was performed using petrographic analysis and X-ray diffraction (XRD) to determine the mineral composition, quantity, and mineral image within the rock samples. Rock strength was assessed through Uniaxial Compressive Strength (UCS) testing to determine the critical stress of the rocks. The findings of this research are expected to provide valuable insights into estimating rock mechanical properties across various applications, particularly in predicting rock responses to external forces.

Method

Rock sample

The samples in this study are extrusive igneous rocks from Bukit Kunyit, located on the southern coast of Bandar Lampung City. According to the Regional Geological Map of Tanjung Karang [12], the study area belongs to the Lampung Formation (Qtl). This formation consists of lithologies such as pumiceous tuff, rhyolitic tuff, welded tuff, tuffaceous claystone, and tuffaceous sandstone. Columnar jointing structures can be observed at the research site. These columnar joints are formed due to contraction processes resulting from the cooling of volcanic rocks, which leads to tensile failure [13]. Columnar jointing is also generally indicative of flow processes in volcanic rocks.

Properties such as color, texture, structure, and composition can be examined to identify a rock's name and type. In Bukit Kunyit, variations in the color of the rocks observed in the field provided a basis for selecting two samples to assess potential differences. The rock samples were thin sectioned for microscopic observation, subjected to X-ray diffraction (XRD) analysis to determine mineral composition, and tested using the Uniaxial Compressive Strength (UCS) method to evaluate rock compressive strength.

Mineral characterization

Mineral characterization of the samples was conducted using petrographic analysis and X-ray diffraction (XRD). Petrography enables the identification of the mineral composition and texture of the rock based on optical properties through microscopic observation, as well as recording two-dimensional images of the rock at specific magnifications. Before observation under a Carl Zeiss polarizing microscope, thin sections were prepared from fresh rock samples, including rocks with weak to strong alteration. The thin sections, with a thickness of 0.03 mm, were placed on slides for viewing under the microscope. Polarizers and analyzers were used to adjust the lighting pattern on the sample to distinguish the minerals. Optical properties of minerals were observed through several steps, including orthoscopic parallel Nicol, crossed Nicol, and conoscopic observation. Minerals were classified as opaque (non-light-transmitting) or transparent (light-transmitting) based on their light transmittance.

X-ray diffraction (XRD) is a material characterization method that leverages the interaction between X-rays and atoms within a crystal system. This technique is widely used to identify crystal lattice types and determine the crystal structure. Additionally, it provides information about the arrangement of different atoms within the crystal [14], [15]. The X-ray diffraction process in a crystal is highly dependent on the crystal structure and the wavelength used, resulting in a characteristic diffraction pattern for each material [16]. The diffracted X-ray beam satisfies Bragg's law, where the reflection of the rays caused by atomic collisions occurs without energy loss, producing elastic reflection. The arrangement of atoms in the crystal enables them to reflect radiation like a mirror, and Bragg's law can be mathematically represented by Equation (1).

$$2d \sin\theta = n\lambda \tag{1}$$

Where λ is the wavelength of the diffracted rays (m), d represents the interplanar spacing (m), n is an integer indicating the order of the diffracted beam (1, 2, 3,...), and θ is the diffraction angle (°).

XRD testing was conducted on rock samples ground into a powder form with particle sizes below 40 microns. Powdered samples offer several advantages; for instance, in powder form, crystal particles are randomly oriented in all directions, allowing X-rays to interact with numerous crystal planes at various orientations. It produces a complete and representative diffraction pattern of the crystal structure. Additionally, more crystal surfaces are exposed to the X-rays, which can enhance the intensity of the diffraction signal, resulting in clearer, more easily analyzed data. The powder X-ray diffraction patterns were obtained using an XRD instrument (Rigaku Smartlab, Japan) with Cu-Kα radiation (1.54 Å).

Uniaxial Compressive Strength (UCS) Test

The uniaxial compressive strength (UCS) test was performed to measure the maximum compressive strength of the rock by applying a load in a single direction. UCS testing is a key parameter for determining rock materials' mechanical properties and failure characteristics [9], [17]. In this test, cylindrical rock samples are placed in a compression testing machine. Proper specimen preparation is essential to ensure accurate dimensions and flat, parallel surfaces so that the load distribution remains even across the sample. Axial pressure gradually applied along the specimen's longitudinal axis until the rock undergoes failure or fractures. The compressive strength is measured at the point of failure (when the specimen breaks or fractures).

At the point of failure, the critical stress of the rock can be calculated, indicating the maximum strength the rock can withstand before breaking or fracturing. Mathematically, this value can be calculated using Equation (2).

$$\sigma_c = \frac{F}{A} \quad (2)$$

where σ_c represents the critical stress or maximum stress (MPa), F is the maximum force applied to the specimen before failure (N), and A is the cross-sectional area of the specimen (m²). The surface area of the specimen is calculated based on its dimensions, using the diameter and height for cylindrical samples or the length and width of the cross-section for cubic or prismatic specimens.

Results And Discussion

Based on macroscopic observation, the rock samples found in the Bukit Kunyit area can be identified as volcanic rocks. The two rock samples exhibit relatively different colors, with one sample having a darker gray shade (Figure 1). Both samples display a vesicular structure (pores formed due to gas release during cooling). Columnar jointing structures were also observed in the rocks from the study area.

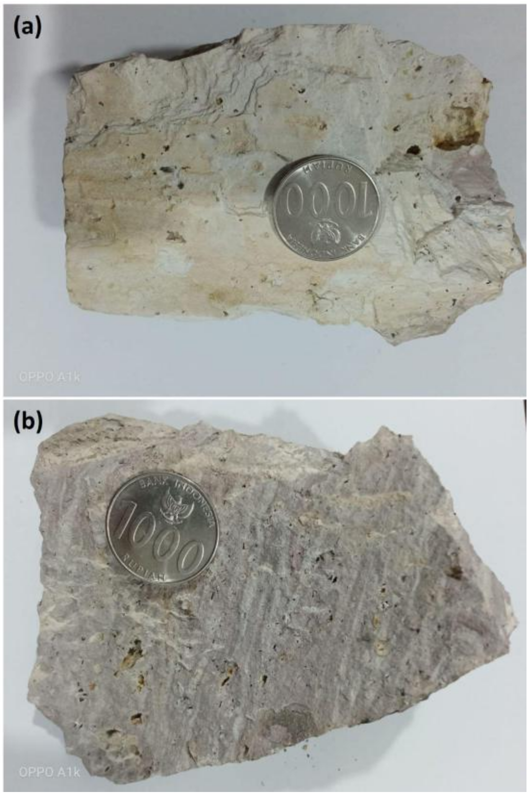

Figure 1. Rock samples (a) Sample 1 and (b) Sample 2.

Petrographic analysis using thin sections shows both rock samples are aphanitic igneous rocks. Approximately 80-90% of the constituent minerals are clay-sized, likely consisting of plagioclase and glass, present as the groundmass. Quartz, biotite, and mica are observed as phenocrysts in both sections. Both rock samples contain 10-15% quartz, but mica is only identified in Sample 2 (Figure 2).

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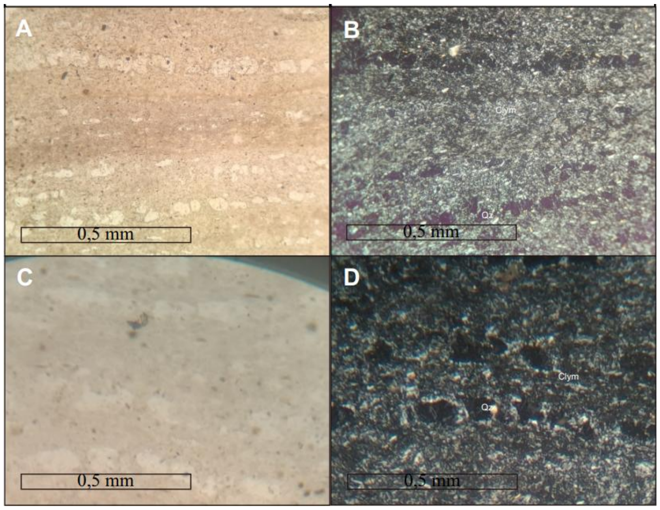

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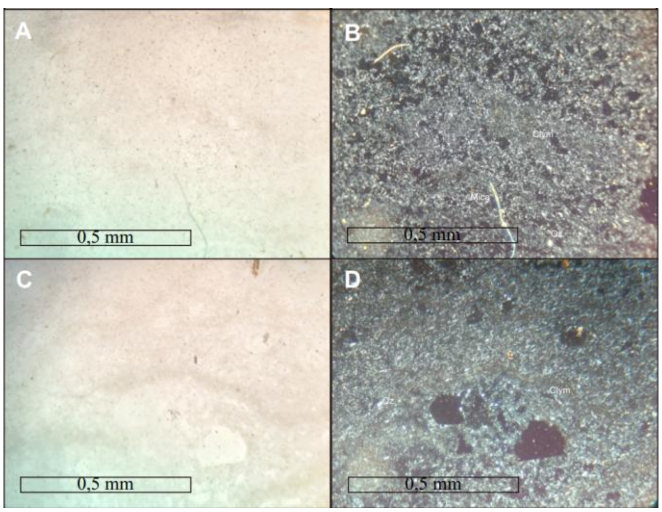

(b)

Figure 2. Petrography of the samples (a) Sample 1 and (b) Sample 2. Sections A and C show images under parallel nicols in each image, while sections B and D show images under crossed nicols. Both samples are dominated by clay-sized minerals, with quartz minerals in crystal forms with angles, and sample 2 also contains mica minerals.

The mineral composition of the rock samples was analyzed using the X-ray diffraction (XRD) method. Before testing, the samples were prepared by grinding them into powder. This was achieved by crushing the samples with a grinder until a minimum weight of 5 grams was obtained. The resulting powder was then analyzed using the XRD method to generate the diffracted wave spectrum. The results of the XRD tests produced diffractograms for both Sample 1 and Sample 2, as illustrated in Figure 3.

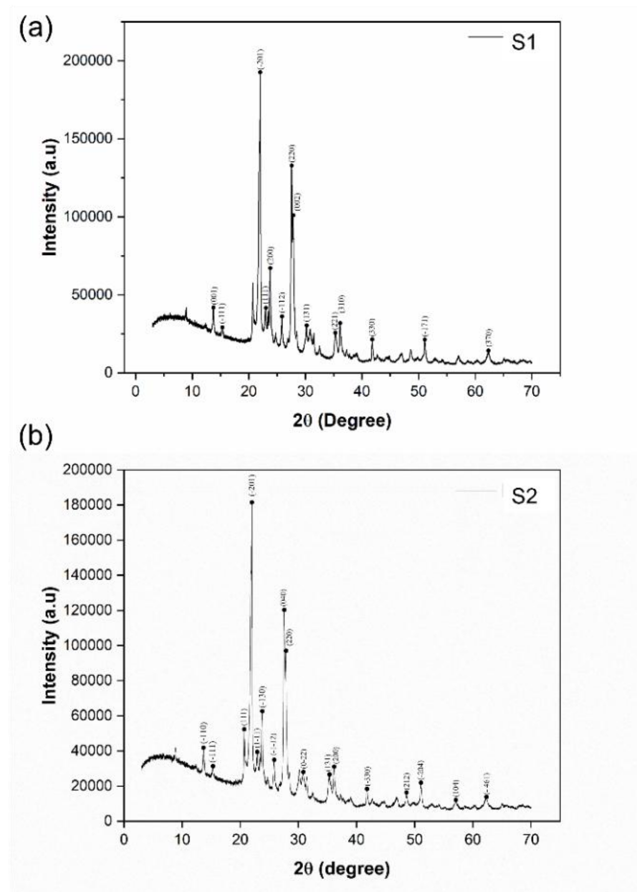

Figure 3. Diffractogram of the samples (a) sample 1 and (b) sample 2.

Based on the test results, both samples have the same mineral variation, namely Anorthoclase, Cristobalite, Tridymite, and Muscovite. These four minerals belong to the silicate group. The mineral identification from the XRD analysis provides additional information that some of the "clay-sized materials" observed in the petrographic examination are composed of plagioclase and glass and include Anorthoclase. A comparison of the mineral percentages between the two samples is shown in Table 1.

Upon comparing the mineral percentages, it is found that both samples exhibit nearly identical mineral compositions. However, a notable difference is observed in the muscovite content, which is greater in Sample 1. This difference implies that the formation of Sample 1 occurred at a lower temperature than that of Sample 2. Both samples are comprised of minerals with high silica content, indicating that the rocks are relatively resistant to weathering. Consequently, the UCS test remains pertinent for determining the critical stress of the samples.

The muscovite present in both samples exhibits variations in density values, diffraction angles, and interplanar distances, though these differences are not substantial. Specifically, muscovite in Sample 1 has a marginally lower density than that in Sample 2. This information is crucial for understanding the rock's strength in withstanding external stresses applied to it.

The lattice indices for each mineral were derived from the information regarding their lattice parameters. Notably, the α and γ parameters of muscovite in both samples exhibit the same values, whereas other lattice parameters display some differences, albeit not significant. These variations in lattice parameters are attributed to fluctuations in pressure and temperature during the formation of the rock.

Table 1. Mineralogical information of the research samples.

No	Sample Code	ICDD Number	Mineral Name	Quantity (%)	Density (g/cm³)	Diffraction Angle (2ϑ)	d-spacing (Å)	Crystal Structure	Lattice Parameter
1	Sample 1	01-075-1631	Anorthoclase (Na0.667 K0.333) (Al Si3 O8)	81.4	2.55	27.45	3.24	Monoclinic	a=8.34 Å α=90.00° b=12.98 Å β=116.10° c=7.15 Å γ=90.00°
		01-071-0785	Cristobalite low (Si O2)	4.8	2.32	21.94	4.04	Tetragonal	a=4.98 Å α=90.00° b=4.98 Å β=90.00° c=6.95 Å γ=90.00°
		01-083-2299	Tridymite (Si O2)	2.3	2.18	20.28	4.37	Hexagonal	a=5.05 Å α=90.00° b=5.05 Å β=90.00° c=8.27 Å γ=120.00°
		01-082-0576	Muscovite 2M1- (K Al2 (Al Si3 O10) (O H)2)	11.5	2.82	34.93	2.56	Monoclinic	a=5.21 Å α=90.00° b=9.03 Å β=95.76° c=20.02 Å γ=90.00°
2	Sampel 2	01-075-1630	Anorthoclase (Na0.667 K0.333) (Al Si3 O8)	88.9	2.58	27.52	3.23	Anorthic	a=8.29 Å α=91.18° b=12.96 Å β=116.31° c=7.15 Å γ=90.14°
		01-082-1403	Cristobalite $-alpha, synthetic (Si O2)	4.6	2.32	21.96	4.04	Tetragonal	a=4.98 Å α=90.00° b=4.98 Å β=90.00° c=6.93 Å γ=90.00°
		01-071-0261	Tridymite (Si O2)	3.4	2.28	20.62	4.30	Anorthic	a=9.93 Å α=90.00° b=17.21 Å β=90.00° c=81.86 Å γ=90.00°
		01-084-1304	Muscovite - (K Al3 Si3 O10 (O H)2)	3.1	2.87	35.28	2.54	Monoclinic	a=5.15 Å α=90.00° b=8.95 Å β=95.75° c=20.07 Å γ=90.00°

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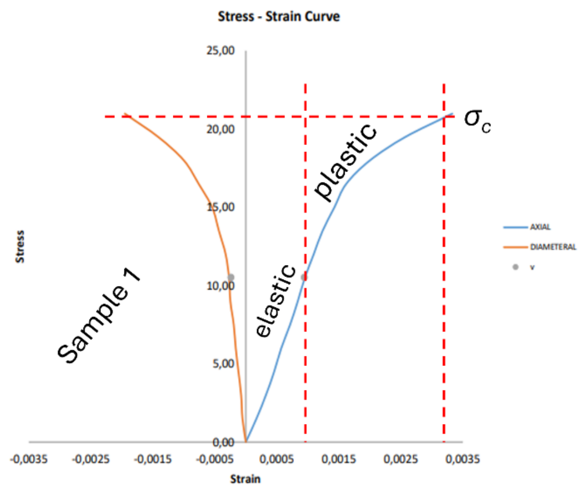
Rock Strength Testing with UCS

The UCS testing was conducted using the ASTM D7012 standard on cylindrical core samples. Both samples had diameters and lengths of 4.61 cm and 10.51 cm for Sample 1, while Sample 2 measured 4.67 cm in diameter and 9.07 cm in length. The testing process involved varying the pressure applied to the samples.

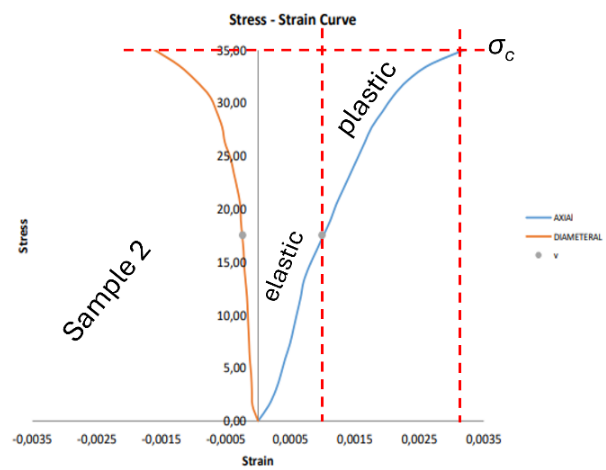
A linear stress-strain relationship was observed at the start of the loading process, where the stress applied to the rock generated strain. At this stage, the rock remains in an elastic state. As applied stress increases, the rock reaches its elastic limit and transitions into the plastic stage, reaching the peak stress before failure, as shown in Figure 5 (stress-strain graph). For Sample 1, the elastic limit occurred at a stress of approximately 11 MPa, while Sample 2 occurred at around 17 MPa. These values represent the Young's modulus of the tested rock samples.

The maximum stress for Sample 1 and Sample 2 occurred at approximately ~20 MPa and ~35 MPa, respectively (Figure 4). After the maximum stress was reached, failure occurred in the samples. Thus, this stress is considered the critical stress of the sample. Test results indicate that Poisson's ratio for Sample 1 is slightly higher than for Sample 2, but Sample 1 has lower Young's modulus and critical stress, as shown in Table 2. The higher Poisson's ratio of sample 1 indicates that this sample tends to undergo greater lateral deformation than Sample 2. Despite the greater lateral deformation, Sample 1 has a lower critical stress. This information suggests Sample 1 is more prone to failure or permanent deformation underloading. Furthermore, Sample 2 shows greater stability under pressure and is less prone to lateral changes than Sample 1, indicating that this rock is relatively stiffer and stronger.

Based on the mineralogical analysis of the rocks, both samples have the same mineral composition, but there is a significant difference in muscovite content. The presence of minerals with low elastic modulus can increase Poisson's ratio but decreases Young's modulus and critical stress. The muscovite content in Sample 1 is relatively higher than in Sample 2. This mineral is suspected to be the reason for the lower critical stress and Young's modulus in Sample 1. The mineral composition of a rock affects its elasticity [18] and strength [19], [20].



(a)



(b)

Figure 4. Stress-strain curve of the UCS test for samples (a) Sample 1 and (b) Sample 2.

Table 2. UCS test results of the rock samples.

No	Sample Code	σc (MPa)	E (MPa)	*v*
1	Sample 1	20.98	11.07	0.245
2	Sample 2	35.05	17.54	0.236

Conclusions

In this study, two rock samples from the same location were analyzed to determine their mineralogy using petrographic methods and X-ray diffraction (XRD). The influence of the rock's mineral composition on critical stress was investigated by conducting unconfined compressive strength (UCS) tests. The conclusions are as follows:

1) Both samples from Bukit Kunyit, Bandar Lampung City, Lampung, display characteristics of rhyolitic rocks predominantly composed of clay-sized materials. The mineral composition of both samples is mainly comprised of silica, which classifies them as siliceous rocks.
2) The mineral content of both samples includes Anorthoclase, Cristobalite, Tridymite, and Muscovite. However, Sample 1 contains a significantly higher proportion of Muscovite compared to Sample 2.
3) Mechanical strength testing reveals that Sample 1 has a critical stress of 20.98 MPa and Young's modulus of 11.07 MPa. In contrast, Sample 2 exhibits higher values, with a critical stress of 35.05 MPa and Young's modulus of 17.54 MPa. Additionally, Sample 1 has a slightly higher Poisson's ratio than Sample 2. This indicates that Sample 2 is relatively stiffer and stronger than Sample 1. The variation in strength is closely linked to the Muscovite content, which is lower in Sample 2 (3.1%) compared to Sample 1 (11.5%). The relationship between the type and total content of each mineral and the rock's critical stress can be further explored through numerical simulations.

Conflicts of interest

There are no conflicts to declare.

Acknowledgments

We are grateful to the Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat, Direktorat jenderal Pendidikan Tinggi, Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi. The financial support awarded through contract number 1570l/IT9.2.1/PT.01.03/2024 has completed this research project.

References

[1] S. Martino, E. Di Luzio, M. E. Discenza, C. Esposito, J. Kundu, and M. Minnillo, "Dataset on physical properties and mechanical parameters of limestone rocks from Central Apennines (Italy) by laboratory test on intact rock specimens," *Data Br.*, vol. 46, pp. 1–7, 2023, doi: 10.1016/j.dib.2023.108886.

[2] G. Eroğlu and A. Çalik, "Relationship of petrographic and mineralogical characteristics with mechanical strength properties of granitic rocks: a case study from the Biga Peninsula, NW Turkey," *Turkish J. Earth Sci.*, vol. 32, no. 1, pp. 126–143, 2023, doi: 10.55730/1300-0985.1831.

[3] R. del Potro and M. Hürlimann, "The decrease in the shear strength of volcanic materials with argillic hydrothermal alteration, insights from the summit region of Teide stratovolcano, Tenerife," *Eng. Geol.*, vol. 104, no. 1–2, pp. 135–143, 2009, doi: 10.1016/j.enggeo.2008.09.005.

[4] S. Uhlemann *et al.*, "Landslide characterization using P- and S-wave seismic refraction tomography — The importance of elastic moduli," *J. Appl. Geophys.*, vol. 134, pp. 64–76, 2016, doi: 10.1016/j.jappgeo.2016.08.014.

[5] D. Wu, B. Li, J. Wu, G. Hu, X. Gao, and J. Lu, "Influence of Mineral Composition on Rock Mechanics Properties and Brittleness Evaluation of Surrounding Rocks in Soft Coal Seams," *ACS Omega*, vol. 9, no. 1, pp. 1375–1388, 2024, doi: 10.1021/acsomega.3c07731.

[6] S. Salimzadeh, E. D. Hagerup, T. Kadeethum, and H. M. Nick, "The effect of stress distribution on the shape and direction of hydraulic fractures in layered media," *Eng. Fract. Mech.*, vol. 215, no. April, pp. 151–163, 2019, doi: 10.1016/j.engfracmech.2019.04.041.

[7] T. Nghipulile *et al.*, "Effect of mineralogy on grindability - A case study of copper ores," *J. South. African Inst. Min. Metall.*, vol. 123, no. 3, pp. 133–144, 2023, doi: 10.17159/2411-9717/1714/2023.

[8] R. M. Tuzingila, L. Kong, and R. Koy Kasongo, "A review on experimental techniques and their applications in the effects of mineral content on geomechanical properties of reservoir shale rock," *Rock Mech. Bull.*, vol. 3, no. 2, p. 100110, 2024, doi: 10.1016/j.rockmb.2024.100110.

[9] S. Narimani, S. M. Davarpanah, L. Kovács, and B.

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Vásárhelyi, “Variation of Elastic Stiffness Parameters of Granitic Rock during Loading in Uniaxial Compressive Test,” *Appl. Mech.*, vol. 4, no. 2, pp. 445–459, 2023, doi: 10.3390/applmech4020025.

[10] Y. Qiao, Z. X. Zhang, and S. Zhang, “An Experimental Study of the Relation between Mode I Fracture Toughness, KIc, and Critical Energy Release Rate, GIc,” *Materials (Basel).*, vol. 16, no. 3, 2023, doi: 10.3390/ma16031056.

[11] V. Donev, O. Lahayne, B. Pichler, and L. Eberhardsteiner, “Ultrasonic characterisation of the elastic properties of mineral aggregates used in asphalt mixtures,” *Road Mater. Pavement Des.*, vol. 25, no. 1, pp. 1–22, 2024, doi: 10.1080/14680629.2023.2188090.

[12] S. Mangga, T. Suwarti, and S. Gafoer, "Peta Geologi Lembar Tanjungkarang, Sumatera, skala 1: 250.000," 1993

[13] A. Lamur, Y. Lavallée, F.E. Iddon, A.J. Hornby, J.E. Kendrick, F.W. Von Aulock, F.B. Wadsworth, “Disclosing the temperature of columnar jointing in lavas, Nat. Commun., 9, 1432,” 2018.

[14] M. R. Setiawan, M. Iqbal, and R. N. Siregar, “Mineral Analysis in Rocks Using XRD and Petrography,” *J. Sci. Appl. Technol.*, vol. 2, no. 1, 2019, doi: 10.35472/281459.

[15] M. R. Setiawan and R. N. Siregar, “Kandungan Mineral dan Struktur Kristal Batu Sekis,” *Sci. Phys. Educ. J.*, vol. 4, no. 1, pp. 24–30, 2020, doi: 10.31539/spej.v4i1.1513.

[16] A. Setiabudi, A. Hardian, and A. Muzakir, *Karakterisasi Material; Prinsip dan Aplikasinya dalam Penelitian Kimia.* Bandung: UPI PRESS, 2012.

[17] W.-Q. Xie, X.-L. Liu, X.-P. Zhang, Q.-S. Liu, and E.-Z. Wang, “A review of test methods for uniaxial compressive strength of rocks: Theory, apparatus and data processing,” Journal of Rock Mechanics and Geotechnical Engineering, p. S1674775524001914, May 2024, doi: 10.1016/j.jrmge.2024.05.003.

[18] M. R. Setiawan, Suharsono, W. Hidayat, Fatkhan, F. D. E. Latief, U. Fauzi, “Elastic properties analysis and characterization of rock ’ s mineral using digital rock image Elastic properties analysis and characterization of rock’s mineral using digital rock image,” in *IOP Conf. Series: Earth and Environmental Science*, IOP Publishing, 2024, pp. 1–7. doi: 10.1088/1755-1315/1437/1/012004.

[19] D. Wu, B. Li, J. Wu, G. Hu, X. Gao, and J. Lu, “Influence of Mineral Composition on Rock Mechanics Properties and Brittleness Evaluation of Surrounding Rocks in Soft Coal Seams,” *ACS Omega*, vol. 9, no. 1, pp. 1375–1388, 2024, doi: 10.1021/acsomega.3c07731.

[20] T. Li, M. Yao, Y. Xie, X. Feng, W. Cong, Y. Shi, and C Tang, “The Influences of Mineral Components and Pore Structure on Hydraulic Fracture Propagation in Shale,” *Rock Mech. Rock Eng.*, no. 0123456789, 2024, doi: 10.1007/s00603-024-04323-5.