

Geochemistry of Granites in Panggong Lalat, Gua Musang, Kelantan

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Abstract. Granites are among the most significant rock formations in the Earth's crust and play a crucial role in various geological processes. This study focuses on examining the geology and granitic rock formations in Panggong Lalat, Gua Musang, Kelantan through field surveys, geological mapping, and geochemical analysis for better understand the geological framework and characteristics of granite in this area. The findings indicate that the lithology of the study area includes granitoids, well-bedded limestone, volcanic rocks, fine-grained sediments, and meta-sedimentary rocks. Petrographic analysis of five samples identified three granitoid types: quartz-rich granitoid, quartz alkali feldspar syenite, and alkali feldspar granite, classified using the IUGS scheme. The X-ray Fluorescence (XRF) data reveals that both samples exhibit typical felsic granite compositions, with high SiO₂ contents in AF 01 (61.61%) and 60.72% in AF02. However, AF 02 displays higher concentrations of TiO₂, FeO, and MnO, suggesting a greater contribution of mafic minerals compared to AF 01. Additionally, CaO content is slightly higher in AF02, indicating a more significant presence of plagioclase feldspar, while AF01 is enriched in K₂O. The Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) data further reinforce the distinction between AF 01 and AF 02. Both samples are enriched in Rare Earth Elements (REE), particularly Ce, Er, and La. A F02 shows significantly higher concentrations of Ce (213.85 ppm) and Er (7554.11 ppm) compared to AF 01 (166.12 ppm for Ce and 3047.54 ppm for Er), indicating a stronger REE enrichment in AF 02. The distribution of Heavy Rare Earth Elements (HREE) is more abundant than that of Light Rare Earth Elements (LREE), with Er exhibiting the highest concentration and Nd the lowest.

1 Introduction

The granitic rocks in Peninsular Malaysia can be divided into three tectonic provinces. The West Coast Province is characterized by the Main Range granite and smaller batholiths such as Taiping, Kledang, Bukit Mertajam, Penang, and Langkawi. The Central Province, situated between the West and East Coast provinces, features a narrow line of plutons extending from

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the Stong Igneous Complex, including the Noring granite near the Thailand border, through Senting, Gua Musang and its surroundings, Damar, Bukit Kajang, and Gunung Benom. Lastly, the East Coast Province includes plutons such as the Boundary Range, Maras-Jerong, Jemaluang, and Muntahak [1]. As granitoid and some intrusive volcanic rocks are widely exposed in Malaysia, as well as Kelantan, this region presents a compelling subject for scientific study and research, particularly concerning the concentrations of rare earth elements (REEs) [2-4]. [5]Granite, the most abundant intrusive rock in the continental crust, is composed primarily of feldspar, quartz, and mica, with a medium to coarse-grained texture. It forms from the crystallization of silica-rich magmas at significant depths within the Earth's crust. Previous research such as [1] suggested Total REE pattern in some granitic rocks in Peninsular Malaysia range from 85.00 ppm to 414.00 ppm. [6] discuss the potential of REEs in Kelantan's granitoid based on their zone covering from western belt, eastern belt to central belt identified substantial concentrations of both light and heavy rare earth elements (REEs) in samples collected from the Central Belt, notably from the Jeli Granite and Berangkat Tonalite formations. The REE are more abundant in the Earth's crust than metals like silver(Ag), copper (Cu), lead (Pb), and mercury (Hg), but typically occur within minerals rather than as pure elements [7, 8]. Their importance in high-tech industries, including superconductors, batteries, magnets, and mobile devices, underscores the need for geological and geochemical analysis. Hence, this study aims to conduct a detailed geological and geochemical investigation of the granites in Panggong Lalat, Gua Musang, Kelantan by applying the combination of petrographic analysis for rock identifications, X-Ray Fluorescence (XRF) for major elements and Inductively Coupled Plasma Optical Emission Spectrometry (ICP- OES) for REE analysis.

2 Methodology

2.1 Thin Section

A thin section is a 30 μm thick slice of rock that is affixed to a glass slide (26 mm x 46 mm in size), using epoxy. The preparation of thin sections involves several specialized tools, including the slab saw, trim saw, grinder, cut-off saw, and lap wheel. The preparation process commences with the adjustment of the glass slide to ensure a consistent thickness. Subsequently, the grinding wheel is cleaned to eliminate any rust. The glass slide is then frosted to create a flat surface, which facilitates effective adhesion of the epoxy. The rock sample is marked according to the intended cutting plane and is initially sliced using the slab saw. The resultant chip is further refined with the trim saw. Following this, the slide is adhered to the chip, after which the chip is removed and the slide is ground to the required thickness. The final procedure involves applying a cover slip to protect the thin section from damage and to enhance its clarity for microscopic analysis.

2.2 X-ray Fluorescence (XRF)

In this method, the preparation of samples begins with the crushing and grinding of granites samples, utilizing either a mechanical grinder or manual tools such as a hammer, mortar, and pestle. The finely ground powder is then carefully transferred into spec-caps using a spatula and subsequently placed into a pressing tool for compaction. A top inlay is applied to seal the powdered material, after which the pressing tool is secured with a plunger. Following this, a pellet press machine is employed to produce compacted pellets. These pellets are then introduced into the XRF instrument for detailed compositional analysis.

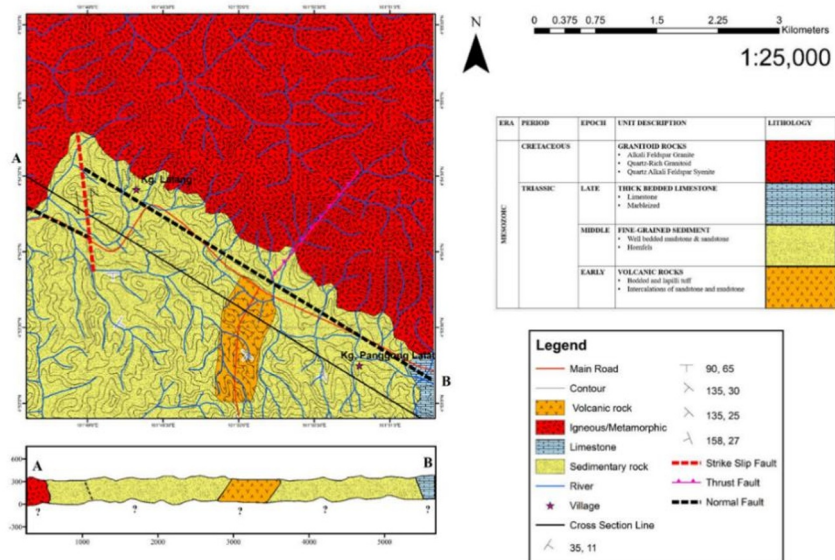
2.3 Inductively Coupled Plasma - Optical Emission spectrometry (ICP-OES)

ICP-OES was used to determine the concentrations of Rare Earth Elements (REEs) in the granitoids samples. The preparation for rock analysis include three parts which are alkaline fusion of rock powders, chromatic separation, calibration of ICP-OES machine for interfered element, interfering element and applying the correction coefficient. The result obtained from ICP-OES analysis yields four different elements, namely, Nd, Ce, La and Er. ICP-OES analysis of rock samples had been carried out at Central Laboratory, Universiti Malaysia Pahang (UMP).

3 Results and Discussion

3.1 Geology of Panggung Lalat

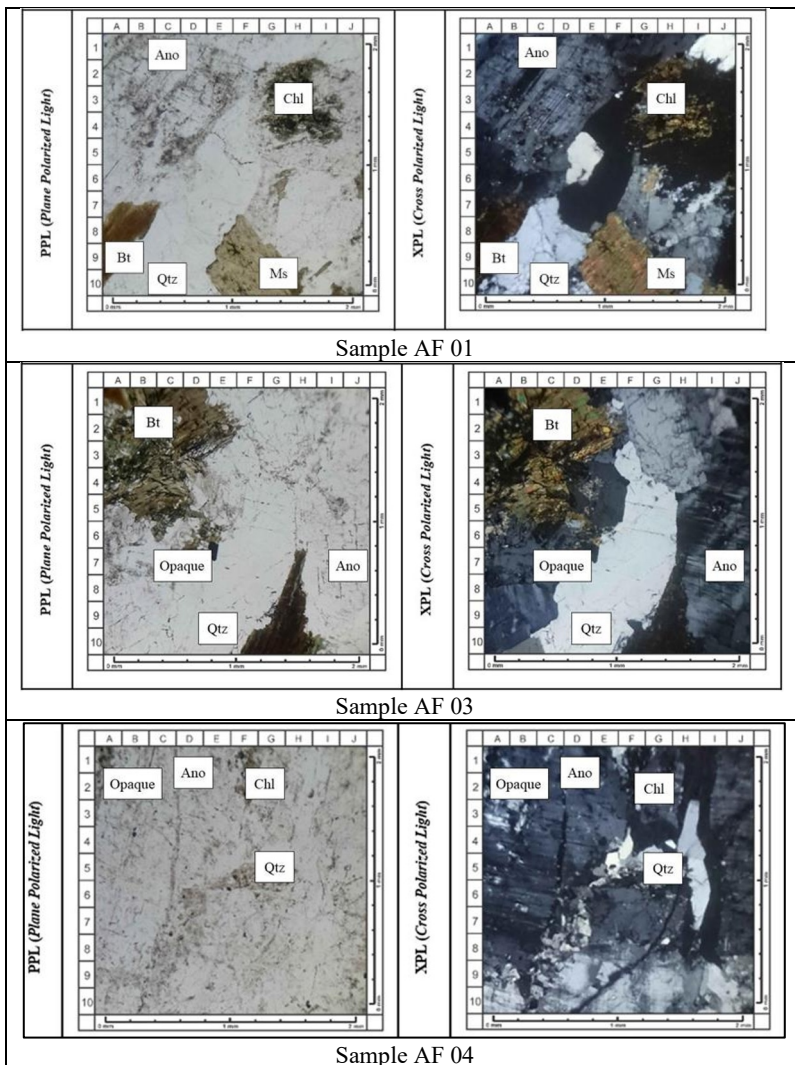
The study area is characterized by two principal rock types: igneous rocks, represented by the granitoid unit, and sedimentary rocks, which comprise both clastic and non-clastic units, as well as deposits of volcanic ash. The igneous rock unit is primarily composed of felsic intrusive rocks, including gray and pink granites. This granitoid unit extensively dominates the northern section of the area, forming a significant batholith that spans approximately 200 km². In contrast, the central to southern part of the study area are predominantly made up of fine-grained sedimentary rocks, characterized by intercalations of mudstone and sandstone. Furthermore, a limestone unit is present in the southeastern part of the study area, complementing the diverse sedimentary rock units, which include non-clastic limestone, clastic fine-grained sedimentary rocks, and volcanic ash deposits, such as bedded tuff and



lapilli tuff.

Fig. 1. Geological Map of Panggung Lalat

For the petrographic analysis of the granites from Panggong Lalat, five granitoid samples: AF 01, AF 03, AF 04, AF 06, and AF 07 were selected for thin section analysis. All samples are coarse-grained with phaneritic textures, indicating a plutonic origin and the intrusive nature of the granitoids. According to the IUGS classification, sample AF01 is identified as Quartz-Rich Granitoid, while sample AF 04 is classified as Quartz Alkali Feldspar Syenite. Samples AF 03, AF 06 and AF 07 are categorized as Alkali Feldspar Granite. The classification was determined based on the mineral content of each sample. Sample AF01 contained a higher percentage of quartz compared to alkali feldspar (anorthoclase), leading to its classification as Quartz-Rich Granitoid when plotted on the QAPF Diagram. Conversely, sample AF04 exhibited a higher percentage of alkali feldspar (anorthoclase) than quartz, resulting in its classification as Quartz Alkali Feldspar Syenite. For samples AF03, AF06, and AF07, the alkali feldspar content was higher than the quartz content. Specifically, sample AF03 contained 47% anorthoclase and 25% quartz, sample AF06 had 61% anorthoclase and 25% quartz, and sample AF07 comprised 39% microcline and 35% quartz. The balance of alkali feldspar and quartz in these samples resulted in their classification as Alkali Feldspar Granite under the IUGS system.



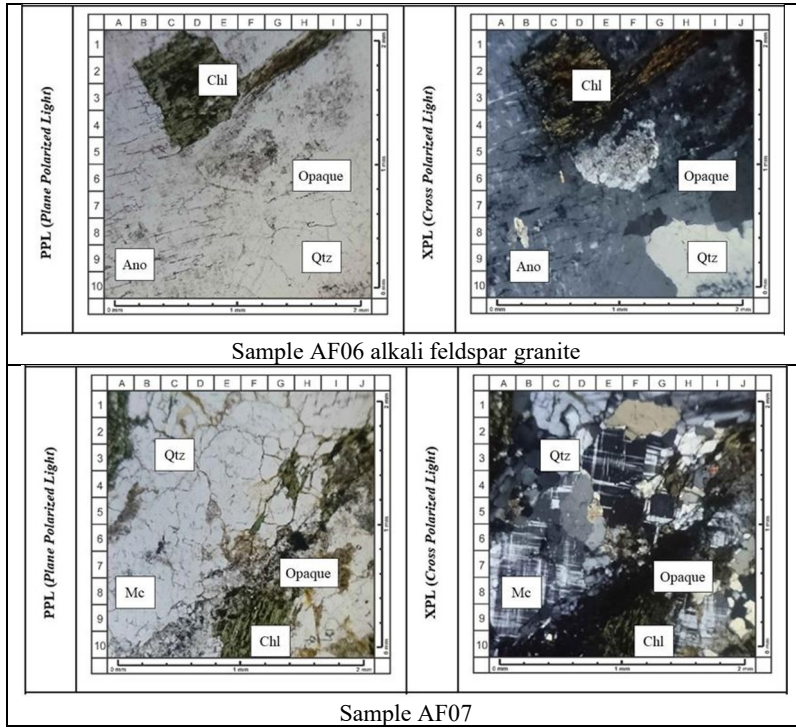


Fig. 2. Petrographic analysis of granite samples.

3.2 Geochemistry analysis

For the XRF and ICP-OES analysis, two samples were selected, for the purposes of the geochemical study. The macroscopic appearances of these samples are depicted in Figure 3 (AF 01) and Figure 4 (AF 02). Table 1 presents the XRF results for the major oxides. The microscopic appearance of AF 01 is classified as Alkali Feldspar Granite, while AF 02 was classified as Quartz Alkali Feldspar Syenite.



Fig. 3. Hand sample AF06 (01)



Fig. 4. Hand sample AF04 (02)

Table 1: Major oxides

Sample	Major oxides (wt%)					
	SiO ₂	TiO ₂	FeO	MnO	CaO	K ₂ O
AF 01	61.6077	1.2409	7.6872	0.1933	7.4237	21.8537
AF 02	60.7240	1.6039	8.7602	0.2754	7.9527	20.6838

Table 1 shows that both samples have a high SiO₂ content of 61.61% in AF 01 and 60.72% in AF 02, suggesting they are felsic in nature. While TiO₂ levels are generally low, as expected for granites, AF 02 has a bit more with value of 1.60% than AF 01 as 1.24%, which might point to more mafic accessory minerals like ilmenite or titanite in AF 02. FeO follows a similar trend, with AF02 with value of 8.76% higher than 7.69% for sample AF 0, suggesting that AF 02 likely has more ferromagnesian minerals such as biotite or amphibole. Both samples show low levels of manganese oxide (MnO), typical for granitic rocks, but the slightly higher MnO in AF 02 (0.27%) compared to AF 01 (0.19%) aligns with its higher FeO content, reinforcing the idea that AF 02 has more mafic components. Calcium oxide (CaO) is moderately present in both samples—7.42% in AF 01 and 7.95% in AF 02—reflecting the presence of plagioclase feldspar, a common mineral in granites. AF 02's slightly higher CaO suggests more plagioclase or possibly some calcium-rich mineral alteration. Potassium oxide (K₂O) stands out in both samples, with high concentrations of 21.85% in AF 01 and 20.68% in AF02.

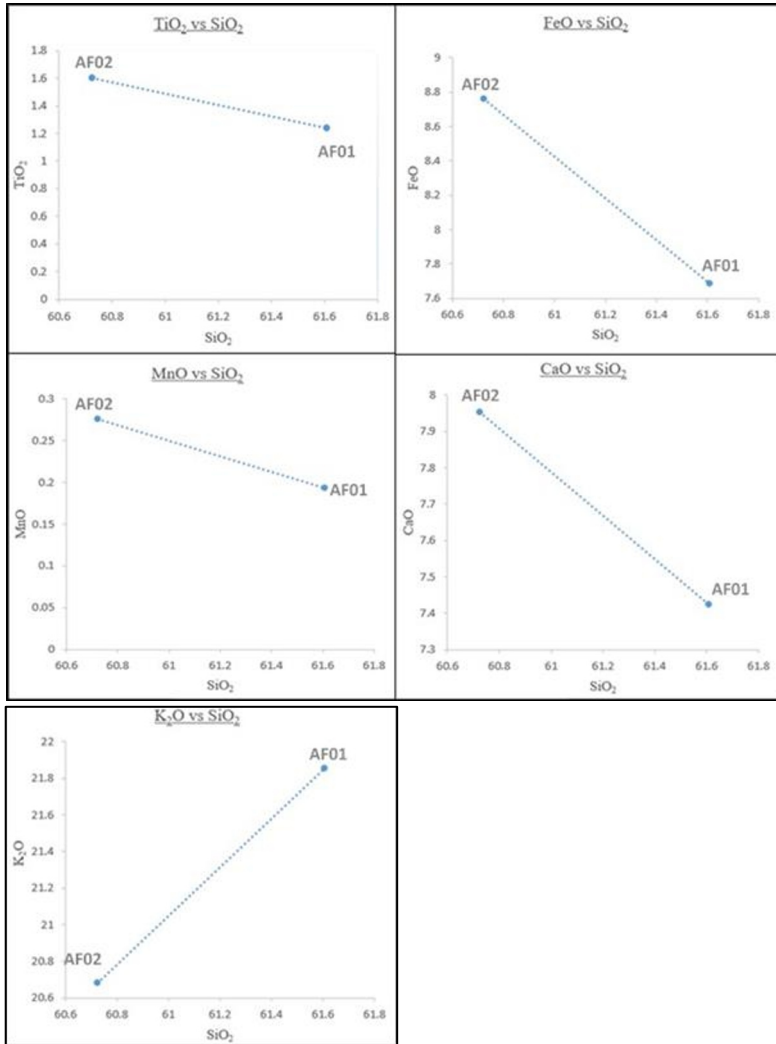


Figure 5: Harker diagram of TiO₂, FeO, MnO, CaO and K₂O versus SiO₂ for sample AF 01 and AF 02

3.2 Rare Earth Elements (REE)

Table 2. Distribution of REE in ppm unit

Elements	(Ce)	(Dy)	(Er)	(Eu)	(Gd)	(Ho)	(La)	(Lu)	(Nd)	(Pr)	(Sm)	(Tb)	(Y)
AF0 01 (ppm)	166.12	n.d	3047.54	n.d	n.d	n.d	150.07	n.d	52.75	n.d	n.d	n.d	n.d
AF 02 (ppm)	213.85	n.d	7554.11	n.d	n.d	n.d	168.83	n.d	63.64	n.d	n.d	n.d	n.d

n.d = not detected (less than 0.1)

The results for samples AF 01 and AF 02 in Table 2 reveal significant enrichment in rare earth elements (REEs) such as Cerium (Ce) Erbium (Er) Lanthanum (La) and Neodymium (Nd). It is noteworthy that AF 02 consistently exhibits concentrations compared to AF 01 across these elements; Er. The levels of which are significantly elevated in AF 02 at 7554.

11 ppm when contrasted with 3047.54 ppm in AF 01 indicating a REE rich geological setting or mineral origin, in AF 02. Some other elements, like Dysprosium (Dy) Europium (Eu) Gadolinium (Gd) Holmium (Ho) Lutetium (Lu) Praseodymium (Pr) Samarium (Sm) Terbium (Tb) and Yttrium (Y) were not detected in the analysis as their concentrations were below the 0.1 ppm possibly due to their occurrence or the limitations, in the method used for analysis. The overall enrichment of light REEs (LREEs) like Ce, La, and Nd, combined with the high concentrations of Er, suggests fractionation patterns that favor these elements, potentially related to magmatic or hydrothermal processes. The geochemical data point to the presence of accessory minerals, such as monazite or allanite, which may host these elements, particularly in AF 02. Further analysis, especially of undetected elements, could provide deeper insights into the processes governing the observed REE distributions.

Conclusion

The geology of Panggong Lalat area is characterized by four lithological units, arranged from youngest to oldest: a granitoid unit (Cretaceous), a thick-bedded limestone unit (Late Triassic), a fine-grained sediment unit (Middle Triassic), and a volcanic rock unit (Early Triassic). Petrographic analysis revealed three distinct types of granitoid, which are classified according to the IUGS system as alkali feldspar granite, quartz alkali feldspar syenite, and quartz-rich granitoid. X-ray fluorescence (XRF) analysis of the major elements indicates that the granite in Panggong Lalat is classified as an S-type granitoid, as evidenced by the K_2O versus SiO_2 plot. Furthermore, Harker diagrams for the six major elements illustrate fractionation trends that may align with the previous finding [2]. The trace element data further reinforce the distinction between AF 01 and AF 02. Both samples are enriched in rare earth elements (REE), particularly Cerium (Ce), Erbium (Er), and Lanthanum (La). AF 02 shows significantly higher concentrations of Ce with 213.85 ppm and Er with 7554.11 ppm compared to AF 01 with 166.12 ppm for Ce and 3047.54 ppm for Er, indicating a stronger REE enrichment in AF02. La follows a similar trend, with sample AF 02 (168.83 ppm) showing higher values than sample AF 01 (150.07 ppm). The enrichment in heavy rare earth elements (HREE) such as Er in AF 02 suggests that this sample has a more pronounced accumulation of REEs, possibly due to different magmatic conditions or mineral assemblages. The absence of detectable levels of other REE (Dy, Eu, Gd, Ho, Lu, Nd, Pr, Sm, Tb, Y) in both samples, with concentrations below 0.1 ppm, may reflect either the limitations of the analytical technique or low natural abundances of these elements in the samples. In conclusion, both AF 01 and AF 02 are felsic granitic rocks, yet they display distinct geochemical characteristics. AF 02 is enriched in mafic components, as reflected by its higher TiO_2 , FeO, and CaO contents, and shows a more substantial enrichment in certain REE, particularly Er and Ce. These geochemical differences between the two samples provide valuable insights into the processes governing their formation and the variability within granitic systems.

We express our profound gratitude to Universiti Malaysia Kelantan for the provision of instruments and resources crucial to this research. We also extend our appreciation to the staff and students of the Geoscience Department, Faculty of earth science, for their valuable contributions. Furthermore, we acknowledge the invaluable assistance of two anonymous reviewers, whose insightful comments and suggestions significantly enhanced the quality of this work.

References

1. W. H. Wan Hassan, M. S. Hamzah, Rare Earth Element patterns in some granitic rocks of Peninsular Malaysia. *Bulletin of the Geological Society of Malaysia*, **43**, 513–528 (1999)
2. S.W.P. Ng, M.J. Whitehouse, M.P. Searle, L.J. Robb, A.A. Ghani, S.L. Chung, G.J.H. Oliver, M. Sone, N.J. Gardiner, M.H. Rosele, *GSA Bulletin*, (2015)
3. M.R. Umor, H. Mohamad, Tren unsur-unsur nadir bumi (REE) Suit Stong, Jeli, Kelantan. *Bulletin of the Geological Society of Malaysia*. **45**. 51-58. (2002).
4. N.S. Shafiee, A.M.A. Bahar, M.M.A Khan, Potential of Rare Earth Elements (REEs) in Gua Musang Granites, Gua Musang, Kelantan 2nd International Conference on Tropical Resources and Sustainable Sciences. *IOP Conf. Series: Earth and Environmental Science* 549 (2020)
5. R. Bonewitz, *Rocks and Minerals* (DK Publishing, 2012)
6. M.F. Patah, N.S. Shafiee, R. Ismail, A.M.A Bahar, M.M.A. Khan, A. Eh Rak, Distribution of light (LHREE) and heavy rare earth elements (HREE) in Kelantan granitoids rock. *IOP Conference Series: Earth and Environmental Science*. 842. (2021).
7. S.B. Castor, L.B. Hedrick, *Rare earth elements*, (Kogel, 2006).
8. V. Balaram, Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental impact, *Geoscience Frontiers*. **10**, Issue 4, (2019)