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Characteristics of pegmatite of Kon Ray, Kontum massif and its potential application in ceramics

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Abstract: *Feldspar is the primary material used in ceramic production, functioning as a flux during the firing process. Most feldspar materials are extracted from pegmatite. Recently, pegmatite bodies have been discovered in the Kon Ray, Kontum, Vietnam, showing potential for feldspar extraction for the ceramics industry. The pegmatite bodies are in the form of elongated veins trending NW-SE, with widths ranging from a few meters to 30 m and extending from 100 m to 1 km. Results of petrological, mineralogical, and geochemical analyses indicate that the pegmatite is milky white to pale pink, containing approximately 70–80% feldspar minerals and about 20% quartz, with shallow muscovite content (< 1%). Geochemical results show that the pegmatite samples have a very high total alkali content from 8.8 to 15.35%, with an average alkali of 11.86% and SiO_2 from 64.1 to 72.7%. Technological samples were tested in the laboratory and a ceramics manufacturing plant and were directly compared with feldspar samples from Phu Tho province. The results indicate that the pegmatite samples from the study area are of exceptionally high quality, equivalent to or better than the Phu Tho samples, meeting the standards of raw materials for industrial ceramics (TCVN 6598:2000).*

Keywords: *Pegmatite, Feldspar, Kontum, Permian-Triassic.*

1. Introduction

Scientists around the world have shown that pegmatites are crystallized from magma. The source of this magma can be from the mantle or molten magma from the earth's crust. Under suitable conditions of temperature, pressure, and saturated steam, the crystals will crystallize and separate from the magma, called fractional crystallization, as geothermal gradients cause crystals to precipitate at the edges of the magma body. For pegmatites formed in mineral cavities, hydrothermal solutions rise through cracks after the magma has cooled. These solutions contact and exchange minerals with the surrounding rocks in a closed system. This process is responsible for the formation of gemstone-bearing pegmatites. This is the source of pegmatites related to gemstones [1]. Pegmatites are crystallized under pressure conditions of 200–500 MPa, with a crystallization temperature of 350–450ºC [2]. Pegmatites are divided into two main groups: “LCT” and “NYF” [3]. In which, LCT pegmatites with the presence of three dominant elements, “lithium, cesium, and tantalum” are often found in association with S-type granites [4, 5] with the origin being metamorphosed sedimentary rocks and I-type granite [6]. NYF pegmatites with dominant elements “niobium, yttrium, and fluorine” are often related to the origin of A-type granites [7] and intracontinental granites [8]. According to the classification system of I-, S-, A-type granites [4-8]: I-type granites are igneous in origin and derived from mantle or deep crustal sources; S-type granites are sedimentary in origin and contain inherited zircon and aluminum-rich minerals; A-type granites are anorogenic and typically form in extensional settings with high heat flow, while intracontinental granites form within continental interiors, often associated with tectonic stability or rifting. The research results from these scientists have significantly advanced the study of pegmatites. Geological surveys at scales of 1:200,000 and 1:50,000 have identified pegmatites associated with late magmatic activities, found independently in regions with metacarbonate and metamorphic formations [9, 10]. In addition, pegmatites in the Kontum area have been studied and divided into three formation stages of 448 Ma, 271 Ma, and 239 Ma by the author himself [11]. The research results show that the study area has two different tectonic magmatic stages (1) the Ordovician-Silurian and (2) the Permian-Triassic. The pegmatite mineral bodies in the Kon Ray area are newly discovered, not overlapping with the authors’ published studies. Therefore, conducting research on material composition, quality assessment and applicability in ceramics of pegmatite in the Kon Ray area will provide new, quantitative documents contributing to the exploration of feldspar minerals for ceramic production in the Southern region.

2. Methodology

The analytical methods used in this study include 1) Thin-section analysis using a polarized microscope to evaluate mineral composition and the mineral symbiotic complex that forms the primary rock for pegmatite bodies; 2) XRF (X-ray fluorescence) method for determining main element composition; 3) ICP-MS (Inductively Coupled Plasma Mass Spectrometry) method for analyzing trace elements; and 4) Testing of technological samples at a ceramic tile factory, where samples are fired to directly compare technical indicators with Phu Tho standard samples and raw materials for manufacturing construction ceramic product, following the norm TCVN 6598:2000 (Figure 1) [12].

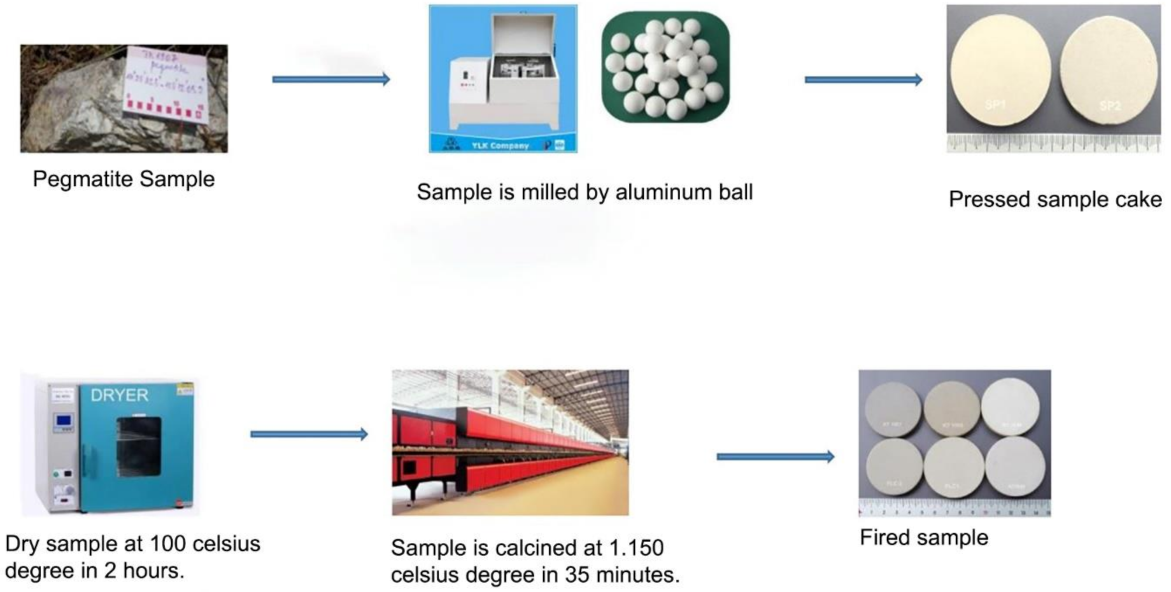

Fig. 1. Testing procedure for firing samples to evaluate raw material at factory.

To evaluate the quality of the samples in the research area and the practical ceramic production capacity of the raw materials, the experimental method involves finely grinding, caking, and firing the samples. These are then compared with the Phu Tho pegmatite standard samples, NA75 and TC08.

3. Results and Discussion

3.1. Geological characteristics of pegmatite mineral bodies

In this study, the authors focused mainly on the Kon Ray district (Figure 2) in Kontum province. The field survey results recorded 8 more pegmatite mineral bodies than the author's previous study [11]. These mineral bodies are distributed along the uplift zone, extending in the NE-SW direction. The uplift zone starts downstream of the Dak Bra river and extends to Mang Den Pass. The age analysis results show that the study area has two magmatic-tectonic stages: the Ordovician-Silurian and the Permian-Triassic [11]. The pegmatite mineral bodies (Figures 3–8) are related to those of the two magmatic-tectonic stages above.

Pegmatite of the Ordovician-Silurian age: accounts for about 30% of the total mineral bodies in the study area. The size of mineral bodies varies from a few meters to about 100 m wide and a few tens of meters to a few hundred meters long, with an extension direction of NE-SW (190–260°). Often found cutting into gneiss, feldspar crystals are pink in color (Figure 3). Feldspar crystals are large from 2 x 3 cm to 4 x 6 cm. Quartz crystals appear interspersed or in veins. Quartz is milky white. Survey results show that the feldspar mineral content in pegmatite mineral bodies of this period has a lower feldspar content than that of mineral bodies in the Permian-Triassic. Pegmatites in this period are 448 Ma (sample KT1903, [11]).

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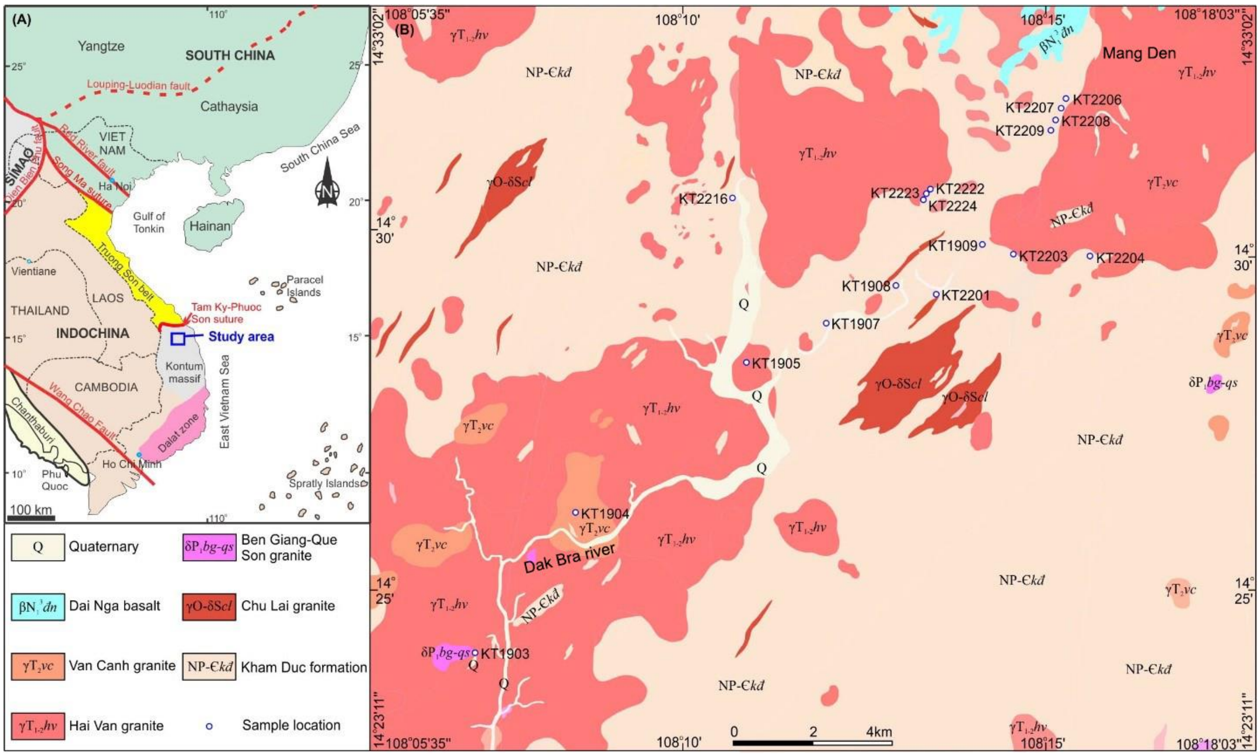

Fig. 2. (a) Geological tectonic framework of Southeast Asia. (b) General outline map of pegmatite in the Kon Ray, Kontum massif; general outline map is based on tectonic and mineralization which was established by Nguyen Xuan Bao [13].

Pegmatite of the Permian-Triassic age: The mineral bodies vary in size, with the width of a few meters to about 100 m, and the length of a few hundred meters to 1 km, with the extension direction of NE-SW (Figure 6, Figure 8). The pegmatite mineral body cuts through Hai Van granite (Figure 4) or covers Hai Van granite (Figure 5). The pegmatite mineral body is milky white, with large feldspar crystals measuring 3 x 5 cm (Figure 5). The mineral composition includes about 80% feldspar, the remaining 20% is lithic, and mica minerals are almost absent. Quartz is clear to opaque white, with large crystal sizes of 4 x 5 cm. (Figure 3). In addition, some pegmatite mineral bodies have garnet crystals measuring 1 x 1cm to 2 x 2cm, the garnet is dark red (Figure 7). Pegmatites of this period have a similar age of 240 Ma (sample KT1904, [11]).

Fig. 3. Pegmatite has pink crystal. It intrudes the gneiss. Sample KT2201.

Fig. 4. Pegmatite intrudes Hai Van complex. Mineral body with 7 m wide.

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Fig. 5. Feldspar crystals has milky white, big crystal. Sample KT2222.

Fig. 6. The body of pegmatite. Sample KT2203.

Fig. 7. Garnet crystal in pegmatite.

Fig. 8. Pegmatite body with ~20m width, ~20m height, and ~500m length.

3.2. Petrographic and mineralogical characteristics of pegmatite mineral bodies

Mineral composition includes potassium feldspar (35–80%), quartz (20–30%), and plagioclase (5–10%), Secondary minerals contain muscovite, kaolin and saussurite.

K-feldspar has very large semi-isomorphous grains, often with no visible grain boundaries in a field (Figure 9). Under plane-polarised light, it is colorless, and opaque due to kaolinization, with a high degree of kaolinization, commonly at 30%. Under cross-polarised light, large K-feldspar grains have intergrown albite plagioclase grains forming a spotted perthite structure (Figure 10). These plagioclase grains have different sizes, and are intergrown to form bands and spots.

Quartz can be divided into two generations. Generation I is characterized by distorted grain shapes, with common sizes around 1mm x 1mm and larger grains reaching 2mm x 3mm (Figure 9, and 11). Under plane-polarised light, the quartz appears colorless with low relief, and under cross-polarised light, it exhibits a gray-white interference color of level I.

Plagioclase can be divided into two generations. Generation I has a semi-isomorphous grain form, with common sizes around 1mm x 1.5mm and the largest reaching 1.5mm x 2mm. Under plane-polarised light, the grains appear colorless with low relief (Ng-Np = 0.007). Under plane-polarised light, the highest interference color is gray-white of the first order, showing a polycrystalline structure according to the albite twin law. Some grains exhibit sericitization, with a high sericitization level of about 60%, mainly concentrated at the grain edges. Generation II has albite plagioclase rays growing into K-feldspar (Figure 11) creating a spotted perthite architecture, common size 0.2 x 0.1 mm, concentrated in strips and stripes.

Muscovite has a flaky form, with common sizes around 0.2mm x 0.1mm, and some samples reaching up to 0.6mm x 0.8mm. These flakes are scattered in the spaces between mineral grains. Under one nicol, muscovite appears colorless with low relief, while Under cross-polarised light, the color changes to a third-order orange-yellow, straight off, C^Ng = 0º (Figure 12).

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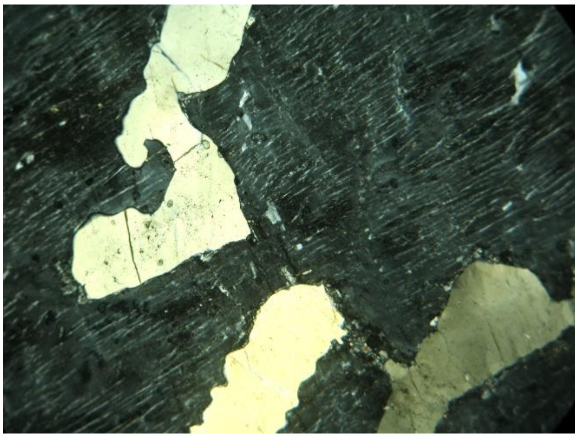

Fig. 9. Feldspar crystal encloses quartz. Sample KT 2207.

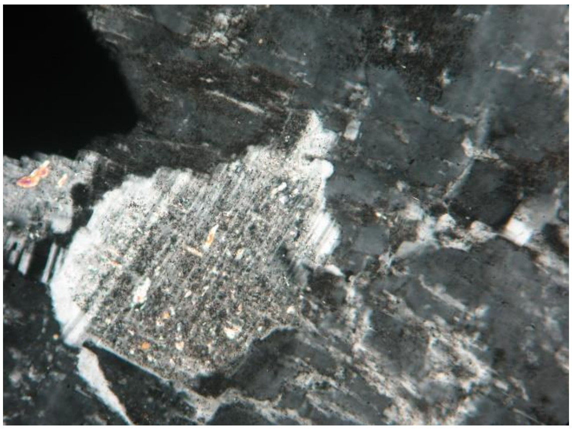

Fig. 10. Feldspar crystal encloses quartz. Sample KT 2207.

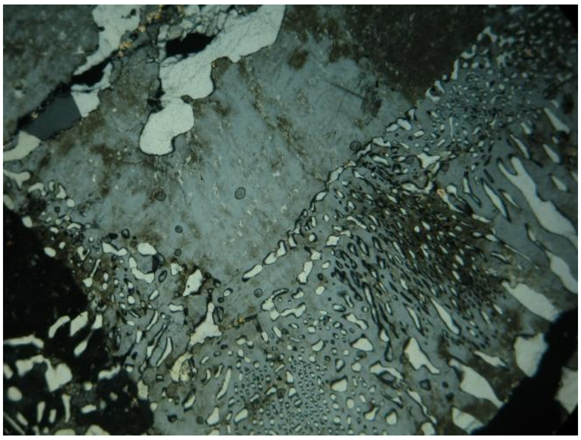

Fig. 11. Pegmatite granophyr texture. Sample KT 2217.

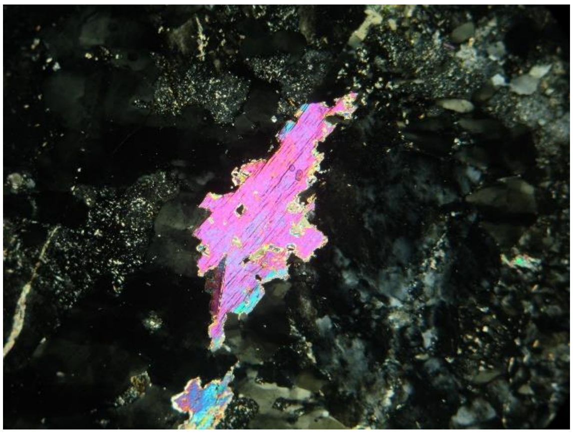

Fig. 12. Muscovite has a subhedral form in pegmatite. Sample 2217.

3.3. Petrogeochemical characteristics of pegmatite

The pegmatite samples are selected for experimental analysis of the major and trace elements from the Kon Ray area, Kontum. The pegmatite samples include 08 samples: KT2222, KT2201; KT2203; KT2204; KT2209; KT2207; KT2223; and KT2204. 02 Phu Tho pegmatite samples also for comparison include NA75 and TC08.

When comparing the results of chemical composition analysis from pegmatite samples in the research area with technical specifications of raw materials for manufacturing construction ceramic products according to the Vietnamese standard TCVN 6598:2000 (Table 1), it shows that:

The average value of silicon oxide content SiO_2 is 70.12%, lower than the allowable limit compared to the Vietnamese standard TCVN 6598:2000 [12] for ceramic bones and slightly higher than the limit for glaze.

Tab. 1. Composition of the pegmatite formation in the Kontum massif based on the results of chemical composition analysis of rocks and comparison of some petrochemical parameters with technical indicators for raw materials for manufacturing construction products according to TCVN 6598:2000

Sample (wt %)	**KT22 22**	**KT22 01**	**KT22 03**	**KT22 04**	**KT22 09**	**KT22 07**	**KT22 23**	**KT22 24**	**Aver age (*)**	**NA75**	**TC08**	**TCV N (**) Glaze**	**TCVN (***) Body**
SiO_2	68.61	64.19	72.79	69.68	70.12	71.06	71.78	72.79	70.12	76.36	77.63	≤ 70	≤ 75
TiO_2	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.05	≤ 0,02	-

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Al_2O_3	16.2	18.60	14.45	16.34	15.66	14.86	14.66	14.7	15.66	14.1	12.73	≥ 16	≥ 14
Fe_2O_3	0.01	0.01	0.01	0.01	0.02	0.01	0.00	0.02	0.01	0.33	0.44	≤ 0,3	≤ 0,5
FeO	0.05	0.08	0.05	0.11	0.14	0.09	0.04	0.21	0.09	-	-		
MnO	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.003	0.0	0.01		
MgO	0.1	0.09	0.09	0.09	0.12	0.09	0.09	0.15	0.10	0.19	0.29		
CaO	0.21	0.14	0.16	0.16	0.18	0.15	0.18	0.98	0.27	0.51	0.39		
Na_2O	1.78	1.17	1.74	2.14	2.34	2.06	2.00	3.34	2.07	6.97	3.25		
K_2O	10.69	14.19	9.24	10.21	9.49	9.62	9.28	5.47	9.78	0.98	4.39		
P_2O_5	0.04	0.08	0.03	0.03	0.06	0.04	0.04	0.05	0.04	0.07	0.08		
LOI*	1.16	0.12	0.96	0.36	1.04	0.61	0.73	1.7	0.86	0.75	0.98	≤ 0,5	≤ 0,5
K_2O+Na_2O	12.47	15.35	10.98	12.46	11.83	11.67	11.28	8.81	11.85	7.95	7.64	≥ 10	≥ 7
K_2O/Na_2O	6.01	12.13	5.32	4.82	4.06	4.68	4.65	1.63	5.41	0.14	1.35		
Q (CIPW)	17.2	2.86	27.27	17.48	20.05	22.32	24.69	30.76	20.34	-	-		
C	1.266	1.28	1.39	1.46	1.36	0.91	1.13	1.66	1.30	-	-		
Or	64.76	85.04	55.41	61.63	57.13	58.0	55.92	33.05	58.87	-	-		
Ab	15.4	10.03	14.09	18.32	20.17	17.74	17.22	28.94	17.84	-	-		
An	0.80	0.17	0.59	0.55	0.56	0.49	0.60	4.63	1.05	-	-		
Di (FS)	0	0	0	0	0	0	0	0	0	-	-		
Di (MS)	0	0	0	0	0	0	0	0	0	-	-		
Hy (MS)	0.244	0.237	0.22	0.23	0.29	0.23	0.22	0.39	0.26	-	-		
Hy (FS)	0.78	0.14	0.07	0.16	0.24	0.15	0.06	0.38	0.16	-	-		
Mt	0.009	0.01	0.009	0.01	0.02	0.01	0.007	0.03	0.01	-	-		
Il	0.02	0.02	0.02	0.03	0.009	0.01	0.02	0.02	0.02	-	-		
Ap	0.09	0.19	0.07	0.07	0.13	0.09	0.10	0.11	0.11	-	-		

**LOI: a loss on ignition*

The average Al_2O_3 content of the samples was 15.66%, reaching the allowable limit for bone standards of ≥14% but lower than the enamel standard of ≥16%. However, the raw materials used for the body accounted for a very high proportion compared to those used for glaze.

The iron oxide content (Fe_2O_3) is below the allowable limit, with an average value of 0.05%. As a result, the fired sample exhibits excellent whiteness, comparable to or even exceeding that of the Phu Tho NA75 and TC08 comparison samples. The color after firing significantly affects the quality of ceramic products. The percentage of muscovite minerals (which contain iron that darkens the fired sample) in the pegmatite samples from the research area is less than 1%, much lower than that of the Phu Tho sample.

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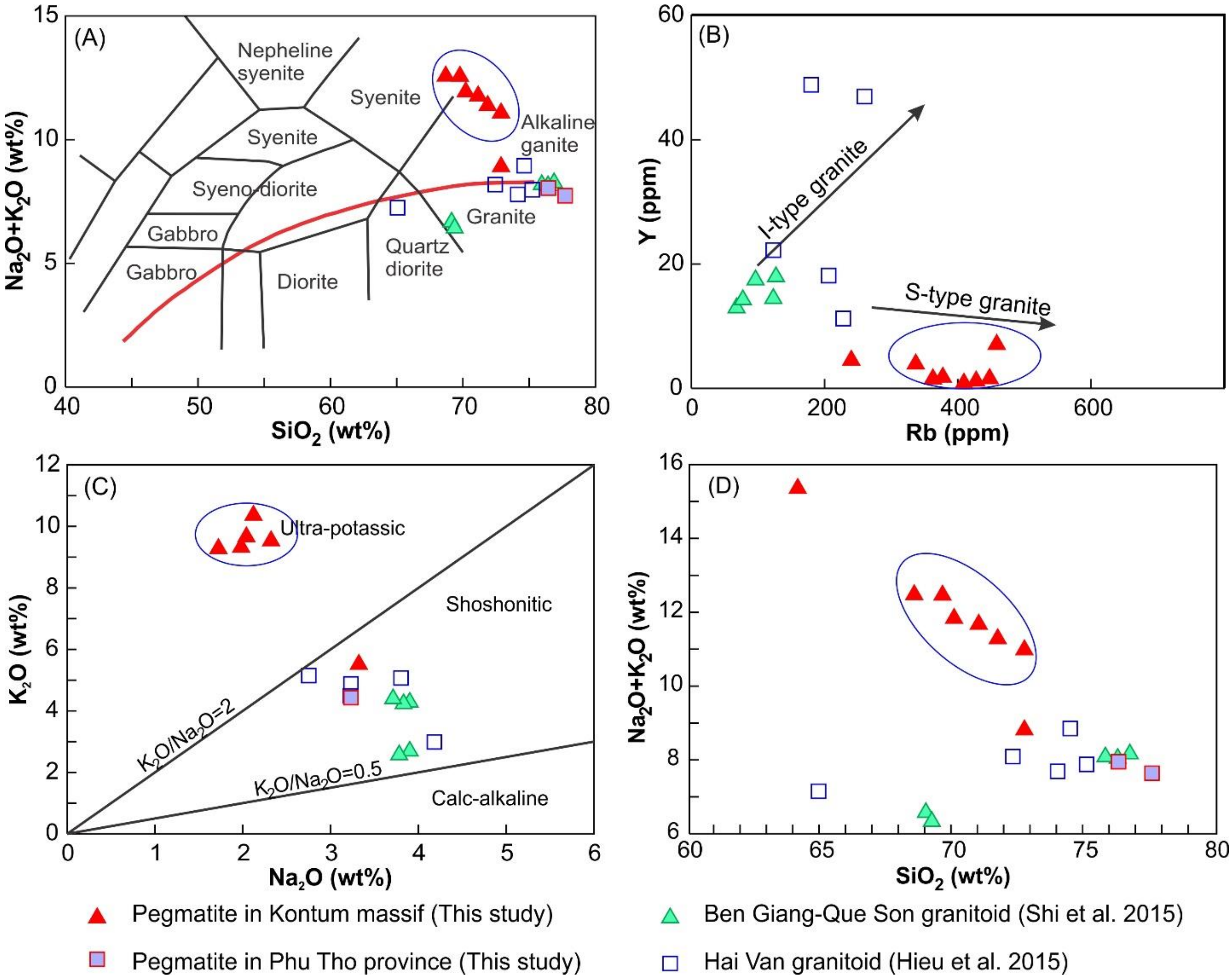

Fig. 13. Classification diagrams of the pegmatite: (a) Total alkali silica diagram [14]; (b) The trend of I- and S-type granites [6]; (c) K_2O vs. N_2O diagram [15]; and (d) SiO_2-vs. (Na_2O+K_2O) diagram for evolution field of pegmatitic magmatism [16].

The iron oxide content (Fe_2O_3) is below the allowable limit, with an average value of 0.05%. As a result, the fired sample exhibits excellent whiteness, comparable to or even exceeding that of the Phu Tho NA75 and TC08 comparison samples. The color after firing significantly affects the quality of ceramic products. The percentage of muscovite minerals (which contain iron that darkens the fired sample) in the pegmatite samples from the research area is less than 1%, much lower than that of the Phu Tho sample.

The loss on ignition (LOI) index does not meet the standard according to the Vietnamese standard TCVN 6598:2000, with the average value of the samples being 0.86. The index exceeds, so it does not affect the quality of the product. In addition, the samples selected for testing in this research were taken near the surface of the pegmatite mineral body, so LOI results are higher.

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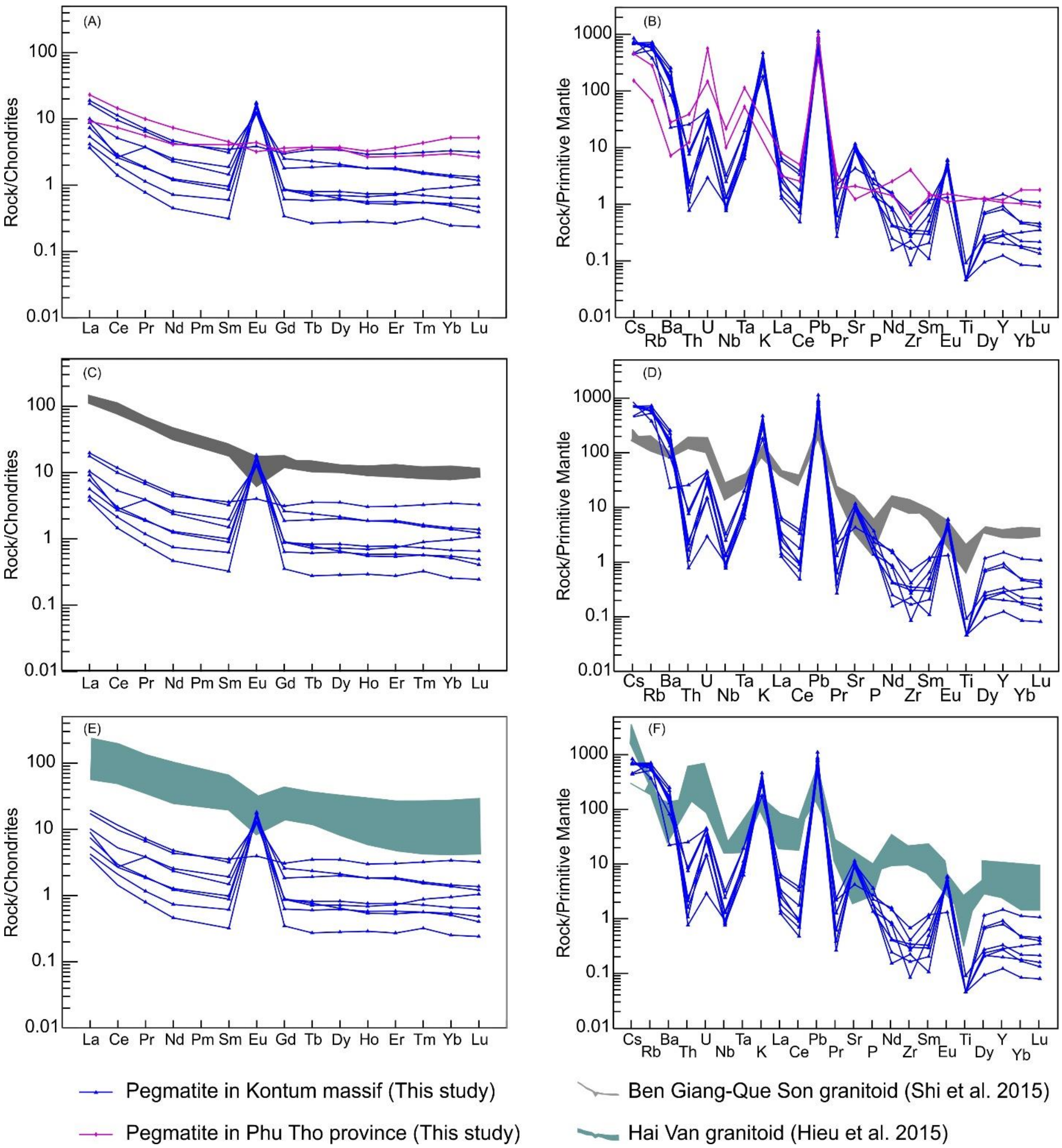

Fig. 14. Chondrite-normalized and primitive mantle-normalized trace element patterns for the pegmatite. Normalization values are from Sun and McDonough (1989)[17].

The geochemical data is from Shi et al. 2015 [18], Hieu et al. 2015 [19] and this study.

The index of total alkalinity content (Na_2O+K_2O) has a very high average value of ~11.85%. Therefore, the samples fall into the alkaline rock field (alkaline granite and syenite) (Figure 13A). This index is crucial because a higher total alkalinity value leads to a lower sample firing temperature, which in turn reduces fuel consumption during the firing process and creates a product with good solidification.

The study area's average K_2O/Na_2O ratio is 15.41, which shows that the pegmatites in this area have a higher potassium oxide content than sodium oxide, i.e., K-feldspar is dominant over Na-feldspar. According to (Figure 13C), the studied samples fall into the Ultra-potassic field.

According to Miyashiro's classification (1974) [20], the studied samples fall into the S-type granite field, which is consistent with the petrographic and mineralogical composition described above (Figure 13B).

The trace element and rare earth compositions of the 8 studied samples and 2 comparison samples, shown on the normalized chart based on the original mantle composition (Figure 14), reveal an increase in mobile petrophilic elements (LILE) such as K, Rb, Ba, Sr, Cs, as well as U and Pb. This suggests that the rocks are related to crustal material sources, either due to contamination during magma migration or because the original material source is linked to crustal composition. On the normalized chart of rare earth elements according to the chondrite composition, the negative slope is a geochemical sign related to the enrichment of LREE elements such as La, Ce, and Nd compared to HREE elements such as Yb, and Lu. This is often the result of magma differentiation. In summary, the trace element and rare earth compositions of the studied samples exhibit key characteristics, including high pegmatite differentiation, consistent with the late stages of acidic magma formation and a feldspar-rich petrographic-lithochemical composition. This may indicate a relationship with crustal material through mixing during magma formation and upward migration.

3.4. Application of pegmatite in ceramic production in the Kon Ray, Kontum massif

In this section, the authors combine the assessments of the content of SiO_2, Al_2O_3, Fe_2O_3, TiO_2 oxides, total alkali content Na_2O+ K_2O, K_2O/Na_2O ratio, and loss index when firing (Section 3.4). The results of testing technological samples are according to TCVN 6598:2000 (Table 2). The technological test samples include 05 single-fired pegmatite samples in the Kon Ray area and 02 Phu Tho samples for comparison (Figure 15). In addition, the fired product samples consist of eight samples: five pegmatite samples, two Phu Tho samples, and one sample from the Y My factory, which is currently in production (Figure 16). The test mix will gradually incorporate the pegmatite samples, which make up 49% of its raw material composition (Mixed sample). The Y My ceramic tile factory, located in Nhon II Industrial Park, Dong Nai, fired all the test samples. The samples were fired in the production kiln, and roller kiln with a firing temperature of 1170ºC and, a firing cycle of 35 minutes. The test results are shown in (Table 2).

- The color after firing of the single firing samples shows that the five samples have an average whiteness of 76.48%. Overall, these test samples exhibit higher whiteness than the standard sample.

- Shrinkage and loss when firing: These two indicators are critical for evaluating the quality of feldspar at high temperatures. The research samples show an average shrinkage of 12.5% and a loss during firing of 1.01%. Additionally, the surface of the sample cakes exhibits a smooth and tightly agglomerated texture, indicating that these samples experience agglomeration at the firing temperature of the factory's production furnace, even though the loss during firing is slightly higher than the standard.

- The results of the firing tests on the sample mixtures indicate that product samples using Kon Ray pegmatite have excellent parameters, such as water absorption, which affects the product's solidity, with an average value of 0.33. This value is nearly three times lower than that of the Y My factory's brick sample and is equal to or better than the two comparison samples.

Fig. 15. Pegmatite samples from Kon Ray area were selected to conduct experiments on technical indicators of ceramic materials according to the Vietnamese standard TCVN 6598:2000.

Fig. 16. The fired product samples consist of eight samples: five pegmatite samples, two Phu Tho samples, and one sample from the Y My factory, which is currently in production.

Tab. 2. Experimental results of technical indicators of raw materials for ceramic production according to TCVN 6598:2000 of some pegmatite samples in the Kon Ray, Kontum massif, and standard samples

Post-calcination criteria / Sample	Shrinkage (%)	Loss of Ignition, LOI (% weight)	Water absorption (%)	Whiteness (%)	notes
Fired sample is tested by producing a kiln roller, banking temperature: 1150^{0}C, cycle 35 minutes.					
KT2201	8.2	0.7	-	82	
KT2204	10.7	0.6	-	83.6	
KT2207	10.2	0.4	-	92.04	
KT2209	10.8	0.9	-	66.4	
KT2222	12.5	0.7	-	58.4	
TS08	12	1.06	-	82	
NA75	12.5	1.01	-	65	
Fixed sample is tested by producing kiln roller, banking temperature: 1150^{0}C, cycle 35 minutes.					
SP1 (KT2201)	-	-	0.15	66.88	
SP2 (KT 2204)	-	-	0.35	68.33	
SP3 (KT2207)	-	-	0.44	70.06	
SP4 (KT2209)	-	-	0.2	69.19	
SP5 (KT2222)	-	-	0.53	66.96	
SP6 (TS08)	-	-	1.3	71.06	
SP7 (NA75)	-	-	0.3	68.89	
Y MY (producing sample).	-	-	0.9	64.5	

4. Conclusion

- The pegmatite mineral bodies in the Kon Ray, Kontum area have large belts in the NE-SW direction, with a width of several meters to several tens of meters and a length of 100 m to 1 km.

- Pegmatite in the research area has the average oxide content: SiO_2 is 70.12%; Al_2O_3 is 15.66%; total alkali Na_2O+K_2O is 11.85%; in which the ratio K_2O/Na_2O = 15.41; Fe_2O_3 content is 0.05; Ti_2O_3 content is

0.01; and technical indicators in technological sample testing such as shrinkage, water absorption, loss on firing and whiteness meet the requirements for raw materials used in the construction ceramic industry - feldspar according to the Vietnamese standard TCVN 6598:2000.

- The pegmatite samples in the study area belong to the alkaline and high alkaline groups, specifically S granite. Their origin may be related to crustal materials through a contamination process that occurred during magma formation and upward movement.

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