

Resources of decorative stones in Bac Kan province, Vietnam

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Abstract: *Bac Kan province locates in the Northeast of Vietnam, formed through geological periods hundreds of millions of years ago. Various thermotectonic activities have resulted in the formation of geological structures, containing different types of rocks, some of which have beautiful colors and can be mined and crafted as products of decorative stones. The combination of endogenous and exogenous activities has created diverse resources of decorative stones in Bac Kan province. On the basic investigation and survey works, sample collection and analysis of material composition, physical and mechanical properties, and artistic quality, several samples have been selected for crafting. As a result, 20 resource sites of decorative stones have been recorded in Bac Kan province. Among these sites, marbles, banded limestones, magmatic and alkaline rocks show promising potential. Most of the decorative stone sites are easily accessible by means of transportation. The great diversity of decorative stone resources also contributes to supporting and promoting local tourism development.*

Keywords: *Resources, decorative stones, Bac Kan, Vietnam.*

1. Introduction

Bac Kan province locates in the Northeast of Vietnam, 170km northeast of Hanoi (Figure 1). Bac Kan has an area of 8 administrative units, including one city (Bac Kan city) and seven districts: Ba Be, Bach Thong, Cho Don, Cho Moi, Na Ri, Ngan Son, Pac Nam ([Statistics office of Bac Kan province, 2023](#)). Bac Kan has complex geological characteristics with the presence of 17 stratigraphic units ranging in age from the Cambrian to Quaternary, composed of terrigenous sedimentary rocks, terrigenous - carbonate, metamorphic rocks such as schist, marble. There are 6 magma complexes: Phia Ma Complex (including alkaline syenite and nepheline syenite); Ngan Son Complex (granites); Cao Bang Complex (gabbro); Nui Chua Complex (gabbro); Phja Bioc Complex (granites); and Cho Don Complex (syenite, granosyenite) ([Department of Geology and Mineral Resources of Vietnam, 2005](#); [Institute of Geological Sciences and Mineral Resources Research, 2014](#); [Quoc, 1974](#)). The combination of endogenous geological processes and exogenous geological processes has created for Bac Kan a potential resource of rocks and decorative stones.

Decorative or ornamental stones have been widely used in Vietnam. However, there is yet to have a national standard for decorative stones, which are, in some ways, still grouped with precious stones. There are many works related to decorative stones in the country (e.g. [Anh et al., 2012](#); [Dung et al., 2019](#); [Dung et al., 2010](#); [Giang & Dung, 2008](#)) and studies on limestone ([Toat et al., 2005](#)), and paving stones in Bac Kan ([Toat et al., 2007](#)). Circular 05/2020/TT-BTNMT of the Ministry of Natural Resources and Environment ([2020](#)) on Technical regulations for exploration and assessment of stone reserves used for tiling and fine arts.

Bac Kan province is rich in carbonate rocks, terrigenous sediments (reddish brown siltstone, claystone), terrigenous carbonate sediments and igneous rocks. Some of precious and decorative stones in Bac Kan province has been marked on the geological map of Bac Kan and neighboring sheets at scale of 1/50.000 such as Thuan Mang gabbrodiabas (Bach Thong district), gabbro (Bang Lung commune, Ba Be district), Bang Phuc syenite and granite (Cho Dien commune, Cho Don district), hydrothermal quartz (Ngan Son district) but they have not been recorded from the perspective of decorative stones.

2. Methods

Methods used in this work include basic field investigations, sample analysis and experimentally crafting. The sample analysis includes thin-section, physical and mechanical properties, and technological characteristics of rocks. The thin-section analysis is to determine the composition of rock-forming minerals, texture, structure characteristics and degree of rock alteration. Analysis of physical and mechanical properties include dry humidity, water absorption, dry and saturated volumetric weight, specific gravity,

porosity, dry and saturated compressive strength, tensile strength, coefficient of consolidation, coefficient of softening, cohesion and internal friction angle, which are parameters to evaluate the ability to meet the requirements of using stones for decorative stones. The methods for processing and crafting stone products involved selecting raw stone samples based on their color, grain, and natural features. Depending on these attributes, the stones were polished or sculpted into various products such as statues or animal figurines.

3. Results and discussion

3.1. Decorative stones of Bac Kan province

The resources of decorative stones of Bac Kan province are shown in Figure 1 and Tables 1 and 2. They include igneous rocks (gabbros, granites, syenites), sedimentary rocks (limestones, banded limestones, banded sandstones), metamorphic rocks (marbles, calciphyre), quartz and precious stones (sapphires), with a total of 20 recorded locations in the districts of Ba Be, Bach Thong, Cho Don, Na Ri, Ngan Son and Pac Nam with the most are concentrated in Cho Don district, followed by Ngan Son district, the least in Na Ri district and absent in Bac Kan city and Cho Moi district.

Tab.1. Resources of decorative stones by districts in Bac Kan province

#	Decorative stones	Districts						Total
		Ba Be	Bach Thong	Cho Don	Na Ri	Ngan Son	Pac Nam	
1	Sapphire	1						1
2	Marbles	1	1	4				6
3	Limestones				1	1	2	4
4	Calciphyre			1				1
5	Sandstones		1					1
6	Quartzs					1		1
7	Gabbro			1		1		2
8	Granite			1		1		2
9	Syenite			1			1	2
10	Granosyenite						1	1
Total		2	2	8	1	4	3	20

Tab. 2. Potential decorative stones in Bac Kan province

#	Decorative stones	Locations
1	Limestone	
	Thon Om limestone mine	Son Thanh commune, Na Ri district
	Ban Tac limestone	Thon Tac village, Duc Van commune, Ngan Son district
	Keo Put banded limestones	Keo Put mine, Nhan Mon commune, Pac Nam district
	Na Quan banded limestone	Co Linh commune, Pac Nam district
2	Marble	
	White Marble	Hoang Tri commune, Ba Be district
	Pink mottled marbles	Na Khoang village, Vu Muon commune, Bach Thong district
	White marbles	Nam Cuong commune, Cho Don district
	White marbles	Ban Chang village, Tan Lap commune, Cho Don district

#	Decorative stones	Locations
	Banded marbles	Phja Khao village, Ban Thi commune, Cho Don district
	White marbles	Ngoc Phai commune, Cho Don district
3	Granite	
	Cho Don Granite	Cho Don district
	Ngan Son granite	Na Khoang village, Na Pac commune, Ngan Son district
4	Gabbro	
	Bang Lung Gabbro	Bang Lung commune, Cho Don district
	Thuan Mang gabbros	Thuan Mang commune, Ngan Son district
5	Syenite and granosyenit	
	Bang Phuc Syenites	Bang Phuc commune, Cho Don district
	Pac Nam Granosyenite	Pac Nam commune, Pac Nam district
6	Other rocks	
	Banded sandstones	Thuy dien village, Vi Huong commune, Bach Thong district
	Calciphyre stones	Ngoc Phai commune, Cho Don district
	Lang Ngam quartzes	Lang Ngam commune, Ngan Son district
	Hoang Tri Sapphire	Na Duong village, Hoang Tri commune, Ba Be district

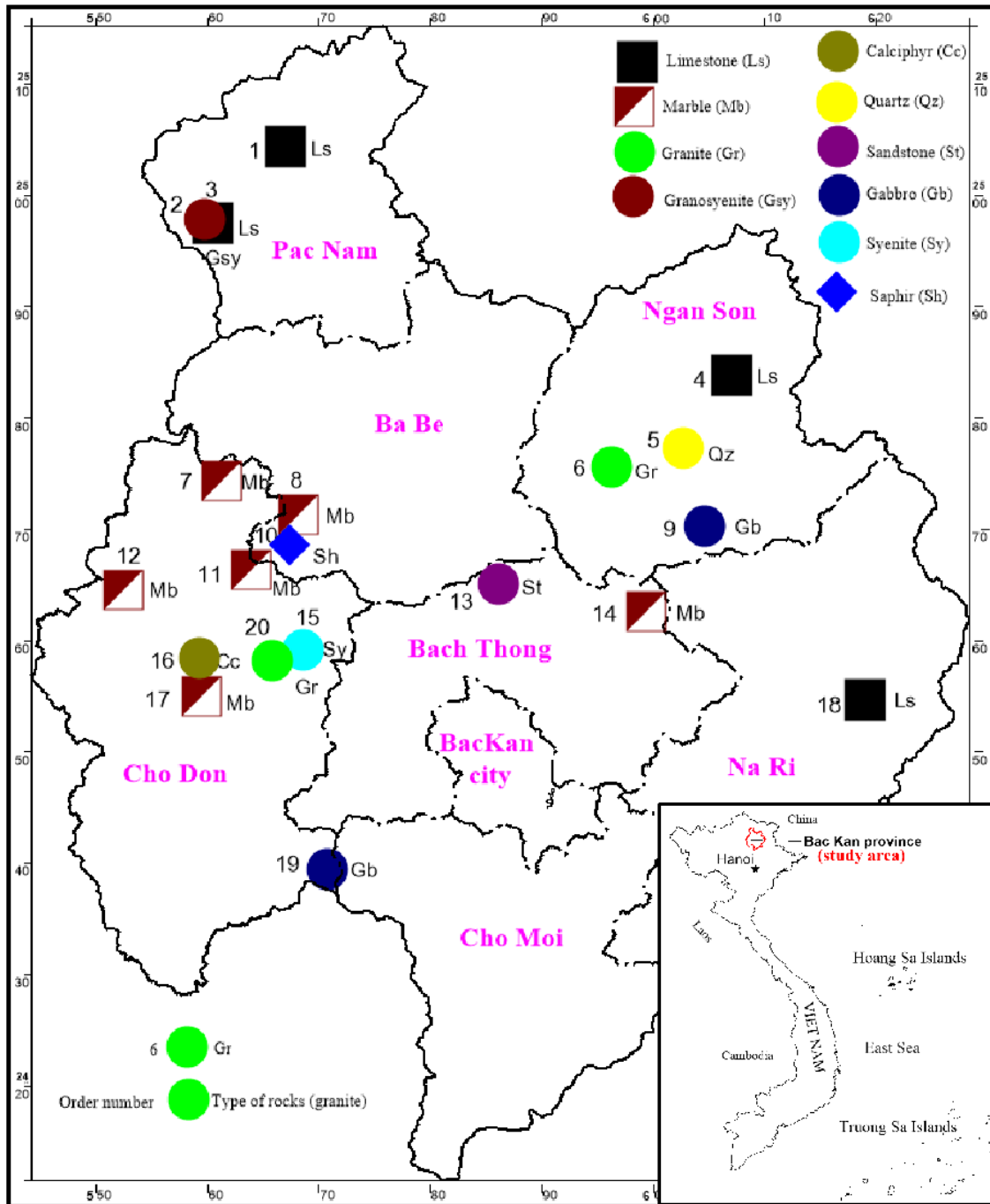


Fig.1. A sketch map showing locations of decorative stones in Bac Kan province

3.2. Limestones

The limestone resources in Bắc Kạn are currently recorded at four sites located in the districts of Na Rì, Ngạn Sơn, and Pác Nặm (Figure 1 and Table 2)

Geological and petrological characteristics: The limestones in Bắc Kạn province belong to various formations, including Mia Le Formation (D_{1ml}) (represented by the Thon Om limestone, located in Sơn Thành commune, Na Rì district); Na Quan Formation ($D_{1.nq}$) (includes the Ban Tac limestone in Đúc Vạn commune, Ngạn Sơn district, and the limestone in Co Linh commune, Pác Nặm district). The limestones are grey, bluish grey, or whitish grey in color. The mineral composition primarily consists of calcite (96–99%), hydroxide, sulphides and organic matter (<1%) (Table 3).

Tab. 3. Geological and petrological characteristics of limestones in Bac Kan province

Limestones	Geological formation	Mineralogy and petrology
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Thon Om limestone mine, (Son Thanh commune, Na Ri district)	Mia Le Formation (D _{1ml})	Recrystallized limestone with mineral composition mainly of calcite, mixed with some organic matter and sulphides sparsely dispersed and attached to calcite bands. Calcite 96-98%, hydroxide ion and organic matter: 1-2%
Ban Tac limestone (Tac village, Duc Van commune, Ngan Son district)	Na Quan Formation (D _{1-2nq})	Recrystallized limestone, consisting of calcite, organic matter and sulphides sparsely dispersed and attached to calcite veins. The rock is oriented and banded unevenly.
Keo Put banded limestones (Keo Put mine, Nhan Mon commune, Pac Nam district)	Mia Le Formation (D _{1ml})	Greenish grey, thick limestones, calcareous claystone. Mineral composition: Calcite: 99%, Hydroxide and sulphides: <1%
Na Quan banded limestone (Co Linh commune, Pac Nam district)	Na Quan Formation (D _{1-2nq})	Grey, blackish grey limestones

Physical and mechanical properties: The results of the analysis of physical and mechanical characteristics of limestones in Bac Kan province are shown in Table 4. The limestones have good physical properties, and meet demand for purpose of making decorative stones.

Tab. 4. Physical and mechanical properties of limestones in Bac Kan province

Physical and mechanical properties	Unit	Location		
		Thon Om (Na Ri)	Ban Tac (Ngan Son)	Keo Put (Pac Nam)
Air dry water content (W)	%	0.04	0.05	0.04
Water absorption (W _{hn})	%	0.26	0.24	0.35
Dry unit weight (γ _C)	g/cm ³	2.70	2.70	2.68
Saturated unit weight (γ _{bh})	g/cm ³	2.70	2.70	2.69
Specific gravity (Δ)	g/cm ³	2.72	2.72	2.72
Porosity (n)		0.74	0.74	1.47
Dry compressive strength (S _{nk})	kG/cm ²	645	623	940
Saturated compressive strength (S _{nbn})	kG/cm ²	596	570	878
Tensile strength (s _k)	kG/cm ²	39	40	74.0
Firmness coefficient (f)	-	6.50	6.25	8.7
Soft coefficient (K)	-	0.92	0.92	0.93
Cohesion (C)	kG/cm ²	85	85	150
Internal friction angle (σ)	Degree	39°59'	39°47'	38°50'

Technological characteristics: The limestones are grey, bluish grey, and whitish grey in color, interspersed with original white bands or patches that are relatively durable over time. Some stones feature patterns, such as black spots or streaks, creating leopard-skin-like or parallel, wavy designs. The stones have a smooth, polished surface, fine grain, and high durability, making them easy to craft. *Block integrity:* limestones have layering thicknesses ranging from medium to thick, commonly 0.2–0.3 meters, and in some areas up to 1 meter. However, in certain regions, tectonic activities have fractured the stone, with cracks filled by secondary calcite. This can affect the physical and mechanical properties, leading to mechanical inhomogeneity and making the stone prone to breaking during processing. The block integrity for pieces larger than 1m³ is generally low.

Potential for exploitation and use as decorative stones: The areas with exposed rocks and quarries have quite good traffic access conditions. Some areas are exploiting limestone for construction materials (such as limestone in Thom Om, Son Thanh commune). Such conditions will facilitate the process of exploiting stone for decorative stone.

Figure 2 shows some decorative products are experimentally crafted from the above limestones in Bac Kan province.



A product of limestones at Pu Mo area (product's height of 0.35m)



A product of limestones at Ban Tac area (the product's length of 0.30m)



A product of banded limestones at Keo Put area (the product's height of 0.25m)

Fig. 2. Products crafted from the limestones in Bac Kan province

3.3. Marbles

The marble resources in Bac Kan are quite abundant, with six recorded distribution sites located in the districts of Ba Be (1 site), Bach Thong (1 site), and Cho Don (4 sites) (Figure 1 and Table 2).

Geological and petrological characteristics: Marble in Bắc Kạn province is distributed across various formations, including the Mia Le Formation (D_{1ml}), which includes marble in Hoang Tri commune (Ba Be district) and in Nam Cuong, Tan Lap, and Ngoc Phai communes (Cho Don district). The Tam Hoa Formation (D_{2-3th}) contains marble in Na Khoang village, Vu Muon commune (Bach Thong district). The marbles are predominantly white, pinkish white, or mottled white interspersed with dolomitic marble. Their mineral composition mainly consists of calcite (97–100%), with minor phlogopite, quartz (Table 5).

Tab. 5. Geological and petrological characteristics of marbles in Bac Kan province

Marbles	Geological formation	Petrology
Hoang Tri commune, Ba Be district	Mia Le Formation (D_{1ml})	White marble contains lenses of dolomitic marble.
Nam Cuong, Tân Lập, Ngoc Phái communes (Cho Don district)	Mia Le Formation (D_{1ml})	Medium to large grain-size marbles. Mineral composition of calcite (98 - 100%), At Ngoc Phai, the marble contains phlogopite.
Na Khoang village, Vu Muon commune, Bach Thong district	Tam Hoa Formation (D_{2-3th})	Pale pink with white blotches marbles.

Physical and mechanical properties: Table 6 presents the results of the physical and mechanical property analysis of marble samples in Bac Kan province. It shows that the physical and mechanical properties of the marble in the province are quite favorable, making the rocks suitable for use as decorative stone.

Tab. 6. Physical and mechanical properties of marbles in Bac Kan province

Physical and mechanical propeties	Unit	Location
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		Hoang Tri	Ngoc Phai	Tan Lap	Nam Cuong	Vu Muon
Air dry water content (W)	%	0.05	0.04	0.05	0.04	0.08
Water absorption (W_{hn})	%	0.22	0.23	0.21	0.26	0.36
Dry unit weight (γ_c)	g/cm^3	2.70	2.70	2.70	2.70	2.67
Saturated unit weight (γ_{bh})	g/cm^3	2.71	2.70	2.70	2.70	2.68
Specific gravity (Δ)	g/cm^3	2.72	2.72	2.72	2.72	2.72
Porosity (n)	-	0.70	0.74	0.74	0.74	1.84
Dry compressive strength (S_{nk})	kG/cm^2	730	623	574	645	1085
Saturated compressive strength (S_{nbh})	kG/cm^2	610	566	518	596	1000
Tensile strength (s_k)	kG/cm^2	58	42	39	39	72.0
Firmness coefficient (f)	-	7.40	6.29	5.70	6.50	9.6
Soft coefficient (K)	-	0.84	0.91	0.90	0.92	0.92
Cohesion (C)	kG/cm^2	120	88	80	85	160
Internal friction angle (σ)	Degree	39°00'	39°39'	39°37'	39°59'	39°35'

Technological characteristics: The marble exhibits various colors, including white, grayish-white, bluish white, red, and reddish pink. Its grain size ranges from fine-grained (e.g., Tân Lập marble) to relatively coarse-grained (e.g., Hoang Tri marble). Fine-grained marble is smoother, more polished, easier to work with, and more durable. **Monolithic integrity:** The marble ranges from moderately layered to blocky, with block thickness varying from 1–2 meters, and occasionally up to 3–4 meters. However, in some areas, tectonic activity has fractured the marble, making it prone to breakage during processing. Consequently, the integrity of blocks larger than 1 m³ is relatively low.

Potential for extraction and use as decorative stones: The exposed marble areas and quarry sites generally have favorable transportation access, allowing vehicles to reach most locations. However, certain sites, such as the Tân Lập marble area, face transportation challenges, requiring consideration of road expansion methods to facilitate transport. Overall, the conditions for extracting marble for use as decorative stone are quite favorable.

Figure 3 showcases some sample products crafted from the marble in Bac Kan province, demonstrating its potential for use in decorative stonework.



A product of marble at Ngoc Phai



A product of marble at Vu Muon (the product's length of 0.25m)

A product of marble at (the product's height of 0.25m)
 Hoang Tri (the product's height of 0.20m)

Fig. 3. Product crafted from the marble rocks in Bac Kan province

3.4. Granite

In Bắc Kạn province, granite resources are abundant, primarily concentrated in two main areas: the granite in Chợ Đồn and the granite in Na Khoang village, Na Pắc commune, Ngan Son district (Figure 1 and Table 2).

Petrographic geological characteristics: granites in Bac Kan province are widely distributed, such as Ngan Son granites, which are distributed on the Phja Bioc mountain range running through Cho Don, Ba Be, and Bach Thong districts. The rocks of the Phia Bioc Complex (γT_3npb) include dark biotite porphyritic granites. Ngan Son granites belong to the Ngan Son Complex (γD_3ns), the main components of which are biotite granites, two-mica granites, aplite, and pegmatite (Table 7).

Tab. 7. Geological and petrological characteristics of granite in Bac Kan province

Granite	Geological formation	Petrology
Cho Don district	Phia Bioc Complex (γT_3npb)	Dark porphyritic biotite granite. Mineral compositions include plagioclase, potassium feldspar, quartz, biotite, accessory minerals: zircon, apatite, ilmenite, pyrite, sometimes tourmaline, magnetite
Na Khoang village, Na Pac commune, Ngan Son district	Ngan Son Complex (γD_3ns)	Biotite granite, two-mica granite, aplite, pegmatite.

Physical and mechanical properties: The physical and mechanical properties of the granites in Bac Kan province are presented in Table 8. The granites are hard, solid, with grain sizes ranging from fine to coarse. Their physical and mechanical properties are excellent, making them suitable for use as decorative stones for artistic and architectural purposes.

Tab. 8. Physical and mechanical properties of granite rocks in Bac Kan province

Physical and mechanical properties	Unit	Location	
		Phia Bioc	Ngan Son
Air dry water content (W)	%	0.08	0.05
Water absorption (W_{hn})	%	0.23	0.16
Dry unit weight (γ_c)	g/cm ³	2.64	2.62
Saturated unit weight (γ_{bh})	g/cm ³	2.65	2.62
Specific gravity (Δ)	g/cm ³	2.65	2.64
Porosity (n)		0.38	0.76
Dry compressive strength (s_{nk})	kG/c m ²	1056	1247.4
Saturated compressive strength (s_{nbh})	kG/c m ²	1013	1212.1
Tensile strength (s_k)	kG/c m ²	72	77.3
Firmness coefficient (f)		9.45	10.61
Soft coefficient (K)		0.96	0.97
Cohesion (C)	kG/c m ²	168	185

Physical and mechanical properties	Unit	Location	
		Phia Bioc	Ngan Son
Internal friction angle (σ)	Độ	39 ⁰ 20'	40 ⁰ 07'

Technological characteristics: The granites are light-colored, including granitic aplite (Ngan Son granite) and granites from the Phja Bioc complex. The Phja Bioc granites are of two types: dark-colored porphyritic granites with coarse and medium grains, featuring prominent white feldspar spots on a dark gray background. These characteristics give the stone a polished, smooth surface with attractive patterns, making it suitable for ornamental blocks and large, relatively simple artistic products such as stone bridges, decorative blocks, bathtubs, and lavabo basins. They are particularly well-suited for high-quality cladding stones. Light-colored granites are ideal for crafting artistic products like statues and lion sculptures. **Block integrity:** The Phja Bioc granites form a large intrusive mass. In streams and rivers, they are exposed as large, solid boulders with high integrity. It is estimated that, upon extraction, over 10% of the blocks will have large dimensions, making them suitable for constructing statues and large artistic structures. On the other hand, the granites of the Ngan Son Complex have smaller exposure areas and are often subjected to compression, leading to a lower recovery rate of large blocks. However, some central (core) areas of the Ngan Son massif meet all the requirements for decorative stone production.

Potential for exploitation and use as decorative stones: The granites in Bắc Kạn are widely distributed across various locations within the province. With favorable transportation conditions, the extraction and transportation of these granites are relatively convenient.

Figure 4 introduces sample products crafted from Phja Bioc granite and Ngan Son granite in Bac Kan province, designed for use as decorative stones.



Products of Phja Bioc granite (each product is 0.30m long) *A product of Ngan Son granite (the product's height of 0.20m)*

Fig. 4. Products crafted from the granites in Bac Kan province

3.5 Gabbros

Resources of mafic rocks (gabbro) in Bac Kan province were recorded at two locations including gabbro in Yen My mafic block (Bang Phuc commune, Cho Don district) and gabbro, gabbro-diorite in Ban Giang area (Thuan Mang commune, Ngan Son district) (Figure 1 and Table 2).

Geological and petrological characteristics: Gabbro at Bang Phuc (Cho Don district): The gabbro rocks in Bang Phuc belong to the Nui Chua Complex (νT_3nnc). The main lithology consists of olivine gabbro and gabbro, with additional diabase veins cutting through the mass. The mineral composition includes plagioclase (50-55%), pyroxene (25-30% to 40-45%), olivine (3-5% to 10-15%), and accessory minerals (ilmenite, apatite and magnetite). Gabbro at Thuan Mang (Ngan Son district): the gabbro rocks in the Thuan Mang area belong to the Nui Chua Complex (νT_3nnc) and include gabbro and gabbro-diorite, with a funnel-like structure (diatreme) (Chi et al., 2004). The mineral composition consists of hornblende (70%), tremolite (5-7%), phlogopite (5-7%), plagioclase (15-20%), and secondary minerals (epidote and chlorite) (Table 9).

Tab. 9. Geological and petrological characteristics of gabbro in Bac Kan province

Gabbros	Geological formation	Petrology
Bang Phuc commune, Cho Don district	Nui Chua Complex (vaT _{3nnc})	Olivine gabbro, gabbro, along with diabase veins cutting through the mass, are present. The mineral composition consists of plagioclase (50-55%), pyroxene (25-30% to 40-45%), olivine (3-5% to 10-15%) and accessory minerals (ilmenite, apatite, and magnetite)
Thuan Mang commune, Ngan Son district	Nui Chua Complex (vaT _{3nnc})	Gabbro, gabbro-diabase, with mineral composition: hornblende (70%;), tremolite (5-7%), phlogopite (5-7%), plagioclase (15-20%) and secondary minerals (epidote and chlorite).

Physical and mechanical properties: Table 6 presents the analysis results of the physical and mechanical properties of gabbro samples from Bac Kan province. The physical characteristics of the gabbro rocks are high, making them suitable for use as decorative stones.

Tab. 10. Physical and mechanical properties of gabbros in Bac Kan province

Physical and mechanical properties	Unit	Location	
		Bang Phuc (Cho Don district)	Thuan Mang (Ngan Son district)
Air dry water content (W)	%	0.07	0.06
Water absorption (W _{hn})	%	0.22	0.14
Dry unit weight (γ _C)	g/cm ³	2.85	3.06
Saturated unit weight (γ _{bh})	g/cm ³	2.86	3.06
Specific gravity (Δ)	g/cm ³	2.87	3.08
Porosity (n)		0.70	0.65
Dry compressive strength (S _{nk})	kG/cm ₂	1619	2123
Saturated compressive strength (S _{nbh})	kG/cm ₂	1450	2024
Tensile strength (S _k)	kG/cm ₂	110	144
Firmness coefficient (f)	-	12.70	15.50
Soft coefficient (K)	-	0.90	0.95
Cohesion (C)	kG/cm ₂	230	320
Internal friction angle (σ)	Độ	39°30'	39°30'

Technological characteristics: The gabbro rocks are dark greenish grey to black in color. The rocks have a fine-grained texture and are durable. When polished, the surface becomes shiny and smooth. The black color is mixed with the white hues of plagioclase, creating an attractive veining pattern when polished. The Bang Phuc gabbro has high homogeneity, and the Thuan Mang gabbro is also less prone to cracking. The recovery rate of large blocks (over 1m²) can reach 20%.

Potential for exploitation and use as decorative stones: The areas where gabbro outcrops are found currently have limited road infrastructure, with many streams and fords to cross. The infrastructure is not yet favorable for efficient extraction, and investment is needed in road development to improve access to the mining sites.

Figure 5 introduces trial products crafted from gabbro found in Bang Phuc and Thuan Mang, used as decorative stones.



A product of Bang Phuc gabbro (the product's height of 0.30m)



A product of Thuan Mang gabbro (the product's height of 0.20m)

Fig. 5. Product crafted from the gabbros in Bac Kan province

3.6 Syenit and granosyenite

Potential resources of syenite and granosyenite in Bac Kan are currently found in two areas: syenite in Bang Phuc commune (Cho Don district) and granosyenite in the Pia Ma massif, Na Pac commune (Pac Nam district) (Figure 1 and Table 2).

Geological and petrological characteristics

Nepheline Syenite in Ban Man (Bang Phuc): To date, the nepheline syenite deposit at Ban Man (Bang Phuc) is unique. The Bang Phuc nepheline syenite massif is located within the geological structure of Northeast Vietnam. Nepheline syenite appears as boulder accumulations on the weathering surface of gabbroic rocks of the Nui Chua complex. The nepheline syenite ore bodies occur as surface layers, either on gently dissected hill slopes or as accumulations in depressions and ravines. Based on the degree of burial, two types of nepheline syenite deposits can be distinguished: (1) Surface accumulations: boulders directly exposed on modern terrain; (2) Buried deposits: boulders buried in weathered surface mixed with clay at depths ranging from 1-2 m to 4-5 m. The nepheline syenite rocks are coarse-grained and light-colored.

Granosyenite in Pac Nam (Pac Nam District): The granosyenite in the Pac Nam area belongs to the Pia Ma Complex ($\xi PZpm$). These intrusive rocks are nearly concordant with sediments of the Pia Phuong Formation (D_{1pp}) and Devonian sediments, causing nephelinization and feldspathization in contact zones. The composition includes granosyenite, granosyenite, and minor alkaline granite. The mineralogical composition is as follows: Quartz: <10%, Plagioclase: 10-15%, Potassium Feldspar: 60%, Hornblende: 13%, Sulphides: 2-3%, Sphalerite: 1%, Cancrinite: 1-2%, Titanite: Minor. (Table 11).

Tab. 11. Geological and petrological characteristics of syenite and granosyenite rocks in Bac Kan province

Syenite and granosyenite rocks	Geological formation	Petrology
Syenite Bang Phuc commune, Cho Don district	Rolling boulders	Nepheline syenite occurs as blocky accumulations on the weathered crust surface of the Nui Chua gabbro Complex. Nepheline syenite is large-grained and light-colored.
Granosyenite <i>Phia Ma</i> at Pac Nam commune, Pac Nam district	Pia Ma Complex ($\xi PZpm$)	Granosyenite, alkali granite, with mineral composition: quartz (<10%), plagioclase (10 - 15%), potassium feldspar (60%), hornblende (13%), sulphides (2-3%), sphalerite (1%), calcinite (1-2%), and sfen (minor).

Physical and mechanical properties : the results of the physical and mechanical analysis of Bang Phuc syenite and Pia Ma granosyenite samples are shown in Table 6. The analysis results of several syenite

samples from the Bang Phuc area indicate good properties, with physical and mechanical properties that fully meet the requirements for producing ornamental stone products.

Tab. 12. Physical and mechanical properties of syenite and granosyenite in Bac Kan province

Physical and mechanical properties	Unit	Rocks, Location	
		Syenite Bang Phuc	granosyenit Pia Ma
Air dry water content (W)	%	0.04	0.06
Water absorption (W_{hn})	%	0.4	0.4
Dry unit weight (γ_c)	g/cm^3	2,65	2,62
Saturated unit weight (γ_{bh})	g/cm^3	2,65	2,62
Specific gravity (Δ)	g/cm^3	2,71	2,70
Porosity (n)		2,2	2.6
Dry compressive strength (S_{nk})	$kG/c m^2$	950	958
Saturated compressive strength (S_{nbh})	$kG/c m^2$	820	827
Tensile strength (S_k)	$kG/c m^2$	71	72
Firmness coefficient (f)		8.79	8.84
Soft coefficient (K)		0,83	0,84
Cohesion (C)	$kG/c m^2$	158	151
Internal friction angle (σ)	Độ	38°50'	38°52'

Technological Characteristics: The Bang Phuc syenite is light-colored, with a white-gray base and black crystals forming a spotted, leopard-skin pattern. The rock has a medium-to-coarse grain structure, is durable, and has a smooth, shiny surface when polished. In terms of ornamental stone, the syenite nepheline in Bang Phuc has an average decorative quality. However, large blocks can be extracted for use in decorative projects such as stone bases, steps, columns, animal statues, and various other stone sculptures. Pia Ma granosyenite is black with white streaks, creating a beautiful pattern. It has a fine grain and high gloss, making it suitable for ornamental stone use. Block integrity: Granosyenite in the Phia Ma area (Cong Bang commune, Pac Nam district) has high block integrity, with stones exposed along streams and hillsides in large sizes. These blocks are rarely cracked, and extraction potential is high. In contrast, Bang Phuc syenite nepheline mainly occurs in rolled boulders.

Potential for exploitation and use as decorative stones: The Bang Phuc syenite nepheline mainly exists in the form of rolled boulders. A significant portion of these rolled boulders has already been extracted and utilized. On the other hand, Pia Ma granosyenite is found along streams and at higher elevations, where transportation access is not very convenient, making extraction and transportation more challenging.

The Bang Phuc syenite and Pia Ma granosyenite have been selected and experimentally crafted into decorative stone products, yielding fairly good quality results (Figure 6).



A product of Bang Phuc syenite (the product's height of 0.30m)



A product of Pia Ma granosyenite (the product's height of 0.30m)

Fig. 6. Product crafted from the syenite andn granosyenite in Bac Kan province

3.7. Other rocks

In addition to the ornamental stones mentioned, other recorded mineral resources in Bac Kan province include: sandstone layers in the Thuy Dien village area, Vi Huong commune (Bach Thong district); calciphyre in Ngoc Phai commune (Cho Don district); quartz in Lang Ngam commune (Ngan Son district); and especially sapphire in Na Duong village, Hoang Tri commune (Ba Be district) (Figure 1 and Table 2).

Geological and petrological characteristics

The banded sandstones are scattered in Vi Huong commune (Bach Thong district), belonging to the Phu Ngu Formation (O_3-S_{1pn}), including sandstones mixed with silt and clay, with mineral compositions including: quartz (65-68%), plagioclase and potassium feldspar (10-18%), biotite and a little fibrolite (2-5%).

The Ngoc Phai calciphyre rock, located in Ngoc Phai commune (Cho Don district), belongs to the Mia Le Formation (D_{1ml}). These calciphyre rocks are primarily composed of epidote and tremolite, with some samples containing calcite and a small amount of quartz. The presence of epidote and tremolite makes these rocks significant in the region, contributing to their geological characteristics.

White quartzes are found in many areas of Bac Kan province. However, significant quartz deposits are concentrated in the Ngan Son district, surrounding the Ngan Son granitoid mass. The quartz appears in large vein-like forms with considerable thickness and is of hydrothermal origin. Additionally, there are quartz accumulations in weathered zones and those of alluvial origin (related to rainwater and temporary flow that transport fragments and blocks of quartz downhill, forming mixed proluvial accumulations). These apQ accumulations are distributed along valley streams, particularly at the stream mouths (Table 13).

The sapphire in Hoang Tri is located in a high valley between mountains, specifically in the cornfields of the people of Ban Duong village. The sapphire occurs as placer deposits on loose sediments of the Mia Le Formation (D_{1ml}), marking the boundary between the Mia Le Formation and the granitoid rocks of the Phia Bioc Complex (γaT_{3npb}). Surrounding the valley are mountain ranges made of light grey limestones, with medium to coarse grain sizes. The valley has relatively flat terrain, with a predominant composition of brown-yellow clay mixed with many pebbles, gravel, and fragments ranging in size from a few centimeters to several tens of centimeters, containing corundum pebbles, iron-brown slag, and sapphire stones.

Tab. 13. Geological and petrological characteristics of other rocks in Bac Kan province

Rocks	Geological formation	Petrology
Banded sandstones (Thuy dien village, Vi Huong commune, Bach Thong district)	Phu Ngu Formation (O_3-S_{1pn})	Grey, brownish grey banded sandstone, mixed with some setstone. Mineral composition: quartz (65-68%), plagioclase and potassium feldspar (10-18%), biotite and a little fibrolite (2-5%).

Calciphyre stones (Ngoc Phai commune, Cho Don district)	Mia Le Formation (D _{1ml})	Calciphyritic rocks have the main mineral composition of epidote and tremolite, some rock samples contain calcite, little quartz
Lang Ngam quartzs (Lang Ngam commune, Ngan Son district)	Veins and boubles	Quartzes are milky white, solid, and hard, with mineral composition includes quartz (95-100%), sericite and clay (1-2%), chlorite (0-2%) and limonite (minor).
Sapphire (Na Duong village, Hoang Tri commune, Ba Be district)	Possibly products of metasomatics between carbonat of Mia Le Formation (D _{1ml}) and Phia Bioc granite (γT _{3npb})	Sapphires in Hoang Tri are currently discovered in the form of placers, buried under corn fields of local people, Sapphires are dark blue, blue-black with size from 0.2 cm to 15 cm

Physical and mechanical properties: the physical and mechanical properties of the sandstone and calciphyre rocks in Bac Kan province are summarized in Table 14. The analysis results for the sandstone and calciphyre samples from the Bach Thong region show quite good physical and mechanical properties. Although there were no direct physical property analyses for the quartz and sapphire from Hoang Tri and Lang Ngan, based on direct observation and a comparative assessment with the sandstone and calciphyre rocks, it is predicted that these materials also possess favorable physical and mechanical characteristics. This suggests they could be utilized for decorative stone production.

Tab. 14. Physical and mechanical properties of other rocks in Bac Kan province

Physical and mechanical properties	Unit	Rocks and location	
		Banded sandstones	Calciphyre Ngoc Phái
Air dry water content (W)	%	0.19	0.06
Water absorption (W _{hm})	%	0.46	0,55
Dry unit weight (γ _c)	g/cm ³	2.86	2,70
Saturated unit weight (γ _{bh})	g/cm ³	2.87	2,70
Specific gravity (Δ)	g/cm ³	2.86	2,82
Porosity (n)		0.00	4,2
Dry compressive strength (S _{nk})	kG/c m ²	466	888
Saturated compressive strength (S _{nbh})	kG/c m ²	420	772
Tensile strength (S _k)	kG/c m ²	52	71
Firmness coefficient (f)		5.49	8.40
Soft coefficient (K)		0.90	0,87
Cohesion (C)	kG/c m ²	88	160
Internal friction angle (σ)	Độ	36 ⁰ 14'	38 ⁰ 49'

Technological Characteristics

The banded sandstone in the Bach Thong area has a brownish-yellow and brown-grey color with horizontal bedding and layered color patterns, creating simple textures. However, the stones have low gloss and their block cohesion is low due to the alternating layers of sandstone with siltstone and claystone. As a result, the quality of the sandstone from this area does not meet the standard for use as decorative stone, and it holds little potential for exploitation

The Ngoc Phai calciphyre has a mottled, patchy or fairly uniform green color. These characteristics have created beautiful patterns for the calciphyre in the Ngoc Phai area, especially those rich in tremolite and epidote. The stone has a small grain structure, which makes it quite durable. When polished, the stone has a shiny, smooth surface, and has a medium to high decorative power, making it suitable for use in various artistic and decorative applications.

The Lang Ngam quartz has a milky white color, a blocky structure, and fine grains. The quartz rocks in Ngan Son area with blocks of several tens of kilograms to several tons in size can be filtered out and carved or polished to make rockery. The remaining stones can be crushed and processed for export as quartz without impurities, making them valuable for various industrial uses.

The Hoang Tri sapphire stones exhibit a variety of colors, including dark blue, grey, opaque white, yellowish grey, and mottled white, with somewhat dull tones. Occasionally, there are beautiful blue sapphires. The stones have a fine-grained texture, which makes them quite durable, and when polished, they present a smooth and glossy surface. The sapphire in Hoang Tri is currently discovered in the form of mineral placer, buried under corn fields. The size of the sapphires ranges from 0.2 cm to 15 cm. These stones are of interest for their aesthetic appeal and durability, making them suitable for gemstone processing.

Potential for exploitation and use as decorative stones:

The stratified sandstone deposits in Bach Thong district have a small thickness and do not feature prominent characteristics. Due to the limited reserves and the lack of notable qualities, these sandstone deposits do not have significant potential for extraction for use in the production of decorative stone. Therefore, they are not considered viable for use in the production of artistic stone products.

The calciphyre deposits in Ngoc Phai have a convenient transportation system, making them accessible for extraction. These calciphyre rocks can be mined using open-pit methods, such as drilling, using expansion powder, and cables. The by-products, including stones that do not meet the required decorative qualities or block integrity, can be utilized as building materials or in chemical applications to enhance the efficiency of the product. This approach allows for more sustainable use of the resource, maximizing its potential while minimizing waste.

The Lang Ngam Quartzite in the form of alluvial deposits is the largest in scale. They are distributed along the riverbanks, close to major roads, with little to no construction, and land mainly used for growing rice and crops. There are very few large-diameter timber trees. The extraction of large quartz blocks from areas used for crops or rice fields has minimal environmental impact. The process of collecting these stones positively contributes to clearing the land, making it easier for land utilization, and reducing the risk of flash floods, which could otherwise negatively affect agricultural land areas. This makes the mining process relatively environmentally friendly while benefiting agricultural practices.

The sapphire deposit at Hoang Tri is located in a high mountain valley, and currently, access to this site is only possible by motorbike along a steep trail. Therefore, transportation conditions for extraction are quite challenging, making it difficult to carry out efficient mining activities in this area. Improved infrastructure and access roads would be necessary to facilitate the extraction process and support further exploration or commercial exploitation of this resource.

Figure 7 shows raw sapphire from Hoang Tri (placer form) and its experimental crafting. Figure 8 introduces products crafted from banded sandstone from Bacch Thong, quartz from Lang Ngam, and calciphyre from Ngoc Phai for ornamental stone production.



Fig.7. The Hoang Tri sapphire before and after crafting under normal light (left) and in transparency under spotlight (right)



A product of Ngoc Phai calciphyre
(The product's length of 0.6m)



A product of banded sandstone at Bach Thong
district (the product's height of 0.25m)

Fig. 8. Product crafted from the other rocks in Bac Kan province

4. Conclusions

Bac Kan province is rich in natural stone resources that meet the standards for creating decorative stones. The most abundant types are white marble, red marble, calciphyre, and others, which serve as raw materials for tiles, decorative stones, sculptures, and more. The igneous rocks, including acidic, alkali-acidic, mafic, and ultramafic types, have beautiful colors and patterns, making them suitable for use in tiles, decorative stones, etc. A few metamorphic rocks with distinctive colors and patterns, such as granitic gneisses and exchange-metamorphosed stones, are also valuable raw materials for the ornamental stone industry.

In the province, 20 decorative stone resource points have been recorded, including igneous rocks (gabbro, granite, syenite), sedimentary rocks (limestone, limestone with layers, shale), metamorphic rocks (marble, calciphyre), quartzes, and gemstones (sapphire). These resources are found in the districts of Ba Be, Bach Thong, Cho Don, Na Ri, Ngan Son, and Pac Nam. Notably, in the area of Ban Duong, Hoang Tri (Ban Be district), there is a sapphire deposit with good quality, which can be crafted into high-value jewelry and sculptures.

Most of the decorative stones have favorable transportation conditions, easily accessible by various means of transport. These resources can be utilized to promote and develop local tourism, combining the exploitation of ornamental stones with tourism marketing to enhance the region's visibility and economic growth

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