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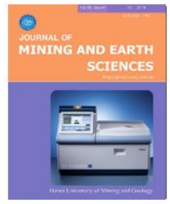

Study on quality characteristics of raw and fine sericite ores in Son Binh area, Ha Tinh province

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ABSTRACT

In this paper, a range of analysis methods (XRD, XRF, SEM-EDS, ICP-MS, and AAS) were used to characterize the quality of Son Binh raw and fine sericite ores. The analytical results indicate that the Son Binh raw sericite ore belongs to a mineral group of sericite - quartz. Non-metallic mineral compositions are mainly quartz, sericite, and pyrophyllite. There are also a number of other minerals with a small content of kaolinite, chloride, and goethite. Son Binh sericite minerals have a fairly fine grain size, with the grain size < 20 µm, about 60%. Harmful metal elements of Cu, As, and Hg have quite strong linear relationships with the correlation coefficients of 0.83, 0.79, and 0.48, respectively. An effective mineral processing was set up with many technological solutions such as selective grinding, gravity separation, flotation, and chemical processing to increase the quality of Son Binh sericite ore. The fine sericites after mineral processing have a good quality with fairly uniform and small size, about 10 mm. Contents of harmful metal elements in the fine sericite (0.34% Pb, 1.8% As and 0.16% Cd) are lower than those in quality regulations. Chemical compositions and other characteristics of the Son Binh fine sericites after mineral processing completely meet quality standards for fields of paint, polymer, and cosmetic production.

1. Introduction

Sericite is known as an alumosilicate mineral group characterized by a thin layer structure. The chemical formula of sericite is (K, Na, Ca) (Al, Fe, Mg)$_2$(Si, Al)$_4$O$_{10}$(OH)$_2$. The chemical composition of a single sericite mineral is SiO_2 = 43 ÷ 49%, Al_2O_3 = 27 ÷ 37%, K_2O + Na_2O = 9 ÷ 11%, H_2O = 4 ÷ 6% (Ciullo, 1996). These chemical compositions vary according to the composition of minerals in sericite, as well as the elements existing in the structure of these minerals. Many sericite deposits with good reserves and quality are prospected, explored and exploited in the world such as in countries of China, Russia, USA, Canada, France, Brazil, Mexico, India, Japan (Altaner and

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Vergo, 1988; Takahisa and Yujin, 1989; Sreenivas et al., 2001). In Vietnam, sericite mineralization is found in many areas such as in La Vang (Quang Tri), Binh Lieu (Quang Ninh), Huong Son (Ha Tinh) (Tran Trong Hue and Kieu Quy Nam, 2006; Pham Tich Xuan et al., 2013; Nguyen Thi Thanh Thao and Ngo Xuan Thanh, 2014). Among the sericite deposits found, Son Binh deposit located in the Huong Son area (Ha Tinh province) is one of the deposits that have a great prospect for sericite with good quality. In recent years, this mine has been explored and exploited in order to supply sericite materials for domestic and foreign markets.

Sericite has many special properties such as lightness, flexibility, electrical insulation, waterproof, non-toxic, inert with chemical environments, preventing ultraviolet rays. Therefore, sericite is considered as an important industrial material and widely used in many fields such as polymers, paints, cosmetics, and high-quality ceramics (Nguyen Van Hanh et al., 2010). Many famous manufacturers using sericite in the world are known as Shanshin Sericite, Myoshi Kasei, Nikko Tokyo (Japan), CAS for cosmetics (Korea), Chuzhou Grea Mineral, Mitsui China (China). Recently, the demand for this mineral in Vietnam is quite large for different applications. Depending on the quality characteristics of each type of sericite in different areas, the sericite will also be used with different functions such as fillers, surface coatings or swelling agents, etc. (Pham Tich Xuan et al., 2014). Therefore, the study on quality characteristics of raw and fine sericite ores is an essential task. Using various analytical methods (X-ray diffraction analysis (XRD), X-ray fluorescence (XRF) method, scanning electron microscopy (SEM-EDS), plasma spectral method - inductively coupled plasma (ICP-MS), atomic absorption method (AAS)) combined with the previous data (Nguyen Van Pho et al., 2014; Pham Tich Xuan et al., 2014; Nguyen Thi Thanh Thao, 2016), the paper shows the quality characteristics of sericite ore before and after mineral processing in Son Binh deposit, Ha Tinh. It will be useful information for the exploitation and effective usage of this sericite.

2. Geological characteristics of Son Binh deposit

In Son Binh deposit, sericite mineralization is located in the rocks of the Dong Trau Formation, the lower sub-formation (T_2 *$ađt_1^2$*) with the main components being tuffs and tuffaceous sediments. Sericite mineralization is discontinuously stretched, forming various mineral bodies with a northwest-southeast direction. The total length of these sericite bodies is more than 4,000m, and their width ranges from 50 to 150m. The rocks of the lower Dong Trau sub-formation are strongly pressed with a dip of 20 ÷ 70° to the southern west (Figure 1). Alteration processes of pyrophylitization and sericitization occur strongly in these rocks, and the sericitic alteration has formed sericite ore bodies. The mineral group in sericite ore in Son Binh deposit is quite simple, mainly including quartz + sericite + pyrophyllite and a small amount of other minerals such as epidote + chlorite + illite + dickite + pyrite + arsenopyrite.

3. Materials and Analytical methods

Raw sericite ore samples were taken at the typical outcrop in Son Binh sericite deposit, Ha Tinh province (Figure 2). The fine sericite ore samples were collected at the Son Binh mineral processing plant. A range of analytical methods, including XRD, XRF, SEM-EDS, ICP-MS, AAS were used to assess the quality of Son Binh raw and fine sericite ores. These methods were carried out at the Center for Excellence in Analysis and Experiment (CEAE) - Hanoi University of Mining & Geology and other laboratories in the country.

4. Results and Discussion

4.1. Characteristics of Son Binh raw sericite ore

4.1.1. Mineral composition

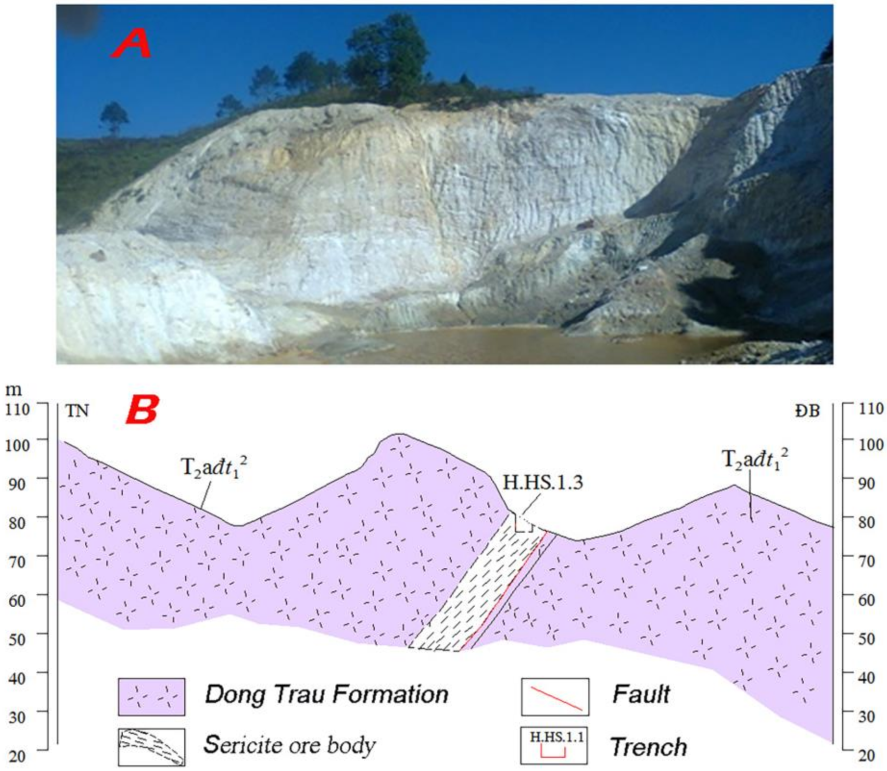

Figure 1. Son Binh sericite deposit. A. A sericite outcrop. B. A geological cross-section line.

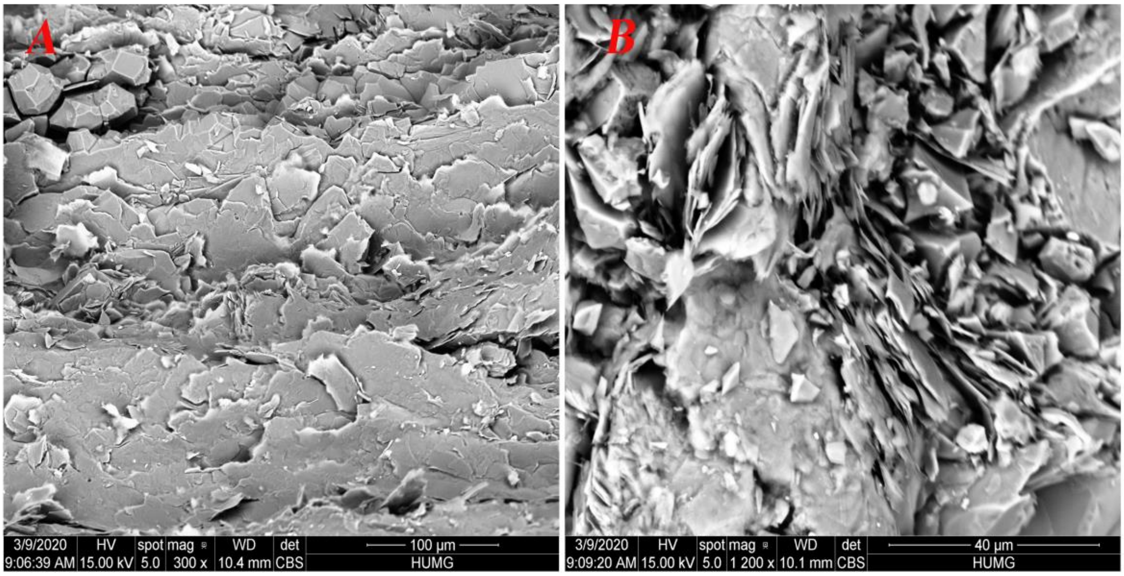

Figure 2. SEM images of the Son Bình raw sericite ore. A. Magnification of 300x; B. Magnification of 1200x.

Previous analysis results showed that rhyolitic tuffs surrounding the sericite zone are composed mainly of non-metallic minerals, accounting for 97÷99%. They consist of main quartz, sericite, and feldspars. These minerals exist in the form of hidden microparticles, scattered with each other. The cohesive material is volcanic ash, which has been transformed into a set of micro-flakes of sericites and clay minerals.

XRD analysis results show that the main mineral composition of Son Binh raw sericite ore

Table 1. Main mineral content in Son Binh raw sericite ore.

Mineral	Content (%)	
	Sample SB-TH1	*Sample SB-TH2*
Sericite	32 ÷ 34	41 ÷ 43
Pyrophyllite	10 ÷ 12	11 ÷ 13
Quartz	47 ÷ 49	41 ÷ 43
Kaolinite + Chloride	3 ÷ 5	3 ÷ 5
Goethite	0 ÷ 0.5	1.0 ÷ 3.0

consists of quartz (41÷49%), sericite (32÷43%), pyrophyllite (10÷13%), kaolinite - chlorite (3÷5%) and goethite (0÷3.0%) (Table 1). The presence of sericite and pyrophyllite minerals clearly reflects the alteration processes of pyrophylitization and sericitization at the deposit. Table 1 also indicates that the quartz content is quite high, and this mineral needs to be reduced during mineral processing.

4.1.2. Chemical composition

The results of the chemical composition analysis of Son Binh raw sericite ores by plasma spectroscopic analysis (ICP) method are shown in Table 2. From Table 2, it has been seen that metal oxide contents of Al_2O_3, Fe_2O_3, and K_2O are 16.20%, 0.23%, and 3.52%, respectively (Table 2). The content of these oxides are relatively small compared to them in a single sericite mineral (Table 3). This may be due to the existence of many kinds of mineral with many different metal oxides in the raw sericite ore. The contents of some heavy metals that affect the quality of sericite such as As and Pb are quite high (As = 31.66 ppm, Pb = 36.82 ppm). Thus, during mineral processing, it is necessary to remove these heavy metals, as well as unnecessary minerals in the raw sericite ore to improve the quality of Son Binh sericite.

Chemical compositions of a Son Binh single sericite mineral are presented in Table 3. The results show that the main element oxide contents of K_2O, Al_2O_3, SiO_2, and H_2O are 9.05 ÷ 10.40%, 35.51 ÷ 37.10%; 45.05 ÷ 47.08% and 4.50 ÷ 5.01%, respectively. It can be seen that these chemical compositions in a single Son Binh sericite mineral have the approximate values in the theoretical sericite mineral.

Table 2. Chemical composition of Son Binh raw sericite ore (ICP-MS analysis).

Oxide	(%)	Element	(ppm)	Element	(ppm)	Element	(ppm)
Al_2O_3	16.20	Ag	< 2	Cu	< 5	Sc	9.11
CaO	0.074	As	31.66	Ga	20.03	Sn	10.75
Fe_2O_3	0.23	B	< 10	Ge	< 20	Sr	29.23
K_2O	3.52	Ba	358.55	La	363.23	Ta	< 10
MgO	0.024	Be	< 5	Li	< 5	V	40.71
MnO	< 0.05	Bi	< 10	Mo	< 5	W	< 20
P_2O	0.005	Cd	< 2	Nb	13.78	Y	52.11
TiO_2	0.63	Ce	117.65	Ni	12.11	Zn	14.33
SiO_2	74.48	Co	2.40	Pb	36.82		
		Cr	17.59	Sb	< 10		

Table 3. Chemical compositions of a Son Binh single sericite mineral.

Sample Name	Oxide content (%)						
	SiO_2	Al_2O_3	MgO	K_2O	FeO	Fe_2O_3	H_2O
SB_TH1/1	46.60	37.08	0.12	10.34	0.20	0.01	4.90
SB_TH1/2	46.91	36.90	0.13	10.27	0.21	0.05	5.00
SB_TH1/3	47.08	37.10	0.10	10.40	0.20	0.03	5.01
SB_TH2/1	45.05	35.51	0.52	9.05	0.10	3.45	4.50
SB_TH2/2	46.96	36.95	0.08	10.12	0.18	2.25	4.98
SB_TH2/3	46.80	36.86	0.26	9.98	0.20	2.13	4.95

4.1.3. Grain siz distribution

The grain size distribution of Son Binh raw sericite ore was defined by using the sieve analysis method according to several grain grades and the natural sedimentation method. The grain size distribution is shown in Figure 3. The figure shows that Son Binh sericites in raw ore have mainly distributed at the grain size < 20 μm, about 60%. Sericite minerals with the grain size > 40 μm account for a small percentage (about 4%). Thus, it can be seen that Son Binh sericite minerals have a fairly fine grain size that can meet the standards of many different applications.

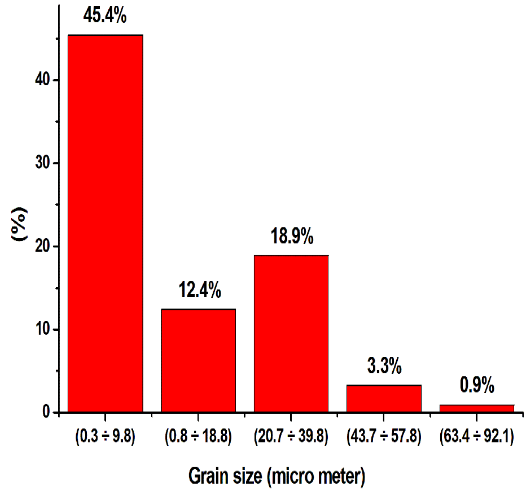

Figure 3. The grain size distribution of sericite minerals in Son Binh raw ore

The results of the analysis of the main chemical components according to different grain sizes of sericite in Table 4 show that the content of oxides varies significantly with grain sizes. The content of quartz increases gradually in large sizes while the content of K_2O and Al_2O_3 increases in the opposite way. Especially, in the fine grain size (<10 μm), the content of K_2O (> 8%) and Al_2O_3 (> 32%) is much larger and SiO_2 content (<52%) is significantly reduced compared to those in Son Binh raw sericite ore. The contents of Al_2O_3 and K_2O in this grain size are approximately 25% and 28%. This is due to that sericite minerals exist mainly in small grain size.

4.1.4. Metal element distribution in Son Binh raw sericite ore

Metal element distribution in the Son Binh raw sericite ore is determined by atomic absorption analysis of 10 metal elements (Cu,

Table 4. Chemical composition in each grain level of Son Binh raw sericite ore.

Grain size level (mm)	Content (%)						
	SiO_2	Al_2O_3	T.Fe[a]	TiO_2	K_2O	Na_2O	LOI[b]
+10	78.61	12.86	0.17	0.58	2.82	0.56	2.70
-10 ÷ +3	78.92	12.29	0.15	0.60	3.24	0.58	2.68
-3 ÷ +1	79.05	12.84	0.17	0.56	3.29	0.73	2.78
-1 ÷ +0.5	77.94	13.75	0.18	0.81	2.36	0.99	2.41
-0.5 ÷ +0.2	76.51	14.20	0.21	1.48	2.45	0.34	2.96
-0.2 ÷ +0.1	75.74	15.24	0.24	0.97	2.48	0.33	3.84
-0.1 ÷ +0.063	76.69	15.33	0.24	0.67	2.48	0.63	3.23
-0.063 ÷ +0.045	77.12	15.12	0.27	0.37	2.24	0.45	2.81
-0.045 ÷ +0.035	76.71	16.18	0.25	0.35	2.36	0.45	2.99
-0.035 ÷ +0.020	76.57	16.62	0.28	0.57	2.80	0.30	1.78
-0.02 ÷ +0.010	73.05	18.80	0.23	0.58	3.51	0.54	2.64
-0.01 ÷ +0.005	53.62	32.46	0.24	0.35	7.82	0.56	4.17
-0.005	48.15	34.08	0.67	0.30	8.62	0.68	6.87

Note: [a]: Total iron; [b]: Loss on ignition

Table 5. The correlation coefficient between metal elements in Son Binh raw sericite ore.

Element	*Cu*	*Pb*	*Zn*	*Mn*	*As*	*Sb*	*Hg*	*K*	*Na*
Cu	1								
Pb	-0.12	1							
Zn	-0.01	0.03	1						
Mn	0.21	0.09	0.76	1					
As	0.83	-0.09	0.24	0.44	1				
Sb	0.08	0.23	0.39	0.57	0.40	1			
Hg	0.48	-0.37	0.40	0.40	0.79	0.30	1		
K	0.30	0.05	0.06	0.22	0.24	0.21	0.04	1	
Na	0.22	-0.24	-0.28	0.11	0.14	-0.16	0.03	0.28	1

Pb, Zn, Cd, Mn, As, Sb, K, Na, and Hg) for fifteen raw sericite ore samples. The analysis results are then used to calculate the correlation coefficient between the metal elements in the Son Binh raw sericite (Table 5) (Davis, 2002).

Table 5 shows that two common elements of K and Na in Son Binh raw sericite ore have a weak linear relationship with other harmful elements. It means that heavy and toxic metal elements do not exist in the crystal network of Son Binh sericite minerals. Three harmful metal elements (Cu, As, and Hg) have quite strong linear relationships with the correlation coefficients of 0.83, 0.79, and 0.48. They have formed into a closed element group of Cu-As-Hg and influence on mineral processing.

4.2. Mineral processing of the Son Binh ore

From the characteristics of Son Binh raw sericite ore, it is shown that an effective mineral processing needs to have the following technological solutions:

- Selective grinding to release sericite minerals into fine and extremely fine grain sizes (10μm);
- Flotation processing to collect sericite in coarse grain size;
- Chemical processing to remove some harmful heavy metals.

A flow-sheet for mineral processing of the Son Binh raw sericite ore is presented in Figure 4.

4.3. Characteristics of Son Binh fine sericite ore

To assess the quality of sericite after mineral processing, the Son Binh fine sericite 1 was collected and analyzed. The scanning electron micrograph (SEM) images and EDS data of the Son Binh fine sericite 1 are shown in Figure 5. From these images, it can be seen that the sizes of the sericite in the sample are fairly uniform and small, with an average size of about 10 mm. EDS spectra show that the main elements in single sericite are Al, Si, O, and their oxide contents are similar to the theoretical chemical formula of typical sericite mineral.

Chemical processing was carried out in conditions of the alkaline solution with 10% NaOH, the solid-phase concentration of 30%, reaction temperature from 40°C and the reaction

Table 6. Content of oxides in Son Binh fine sericite.

Chemical composition $\frac{min \div max}{average}$ (%)						
SiO_2	Al_2O_3	TiO_2	T.Fe[a]	K_2O	Na_2O	LOI[b]
$\frac{60.24 \div 69.64}{64.26}$	$\frac{21.68 \div 30.63}{24.98}$	$\frac{0.09 \div 0.41}{0.25}$	$\frac{0.05 \div 0.22}{0.13}$	$\frac{5.01 \div 5.83}{5.44}$	$\frac{0.13 \div 2.69}{1.54}$	$\frac{1.19 \div 4.24}{2.82}$

Note: [a]: Total iron; [b]: Loss on ignition

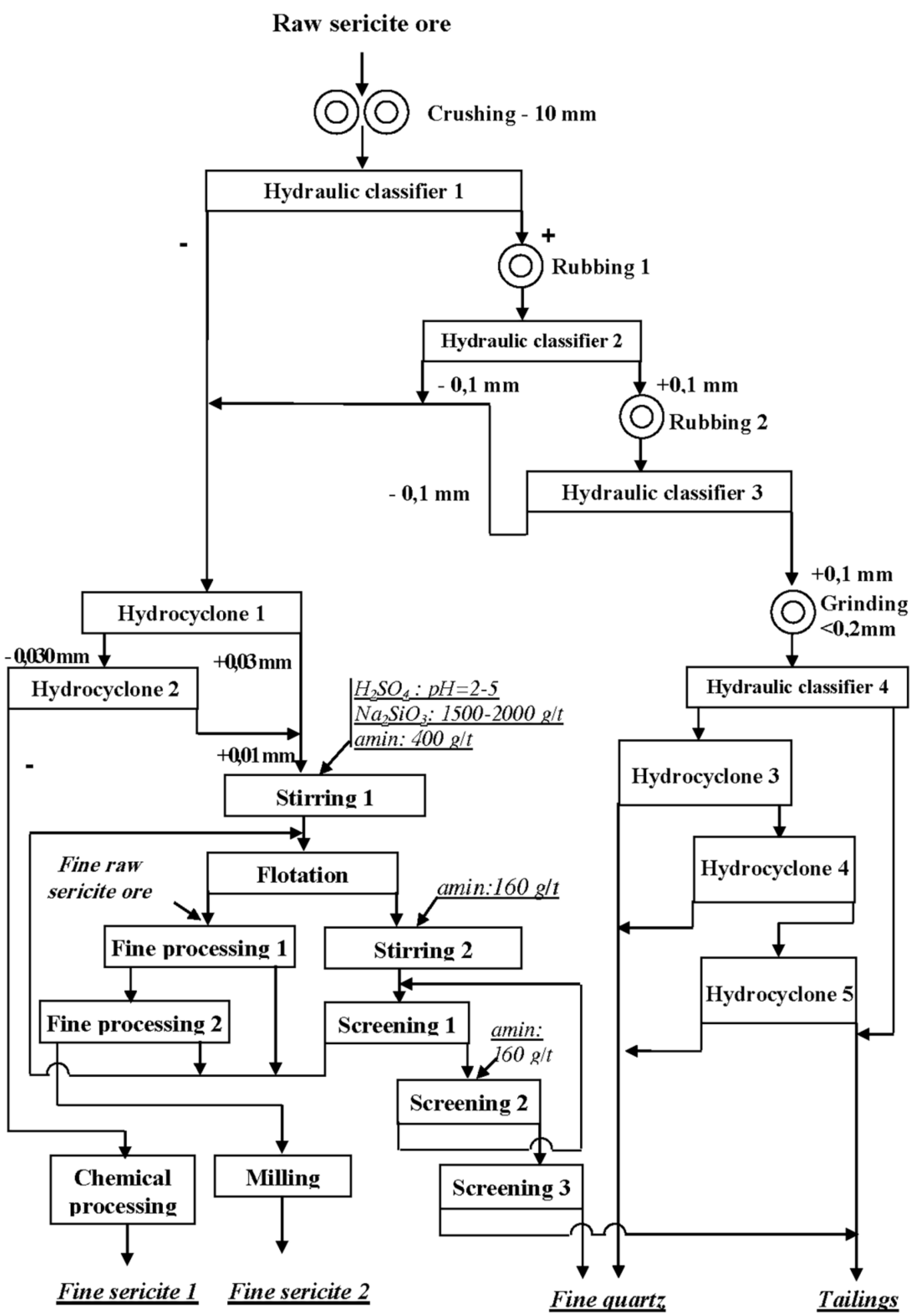

Figure 4. Flow-sheet for mineral processing of the Son Binh raw sericite ore.

time of 120 minutes. The product of fine sericite 1 after chemical processing contains 0.34% Pb, 1.8% As, and 0.16% Cd. Chemical compositions of 19 fine sericite samples show that the content of oxides had a significant change, compared with the Son Binh raw sericite ores (Table 6). For

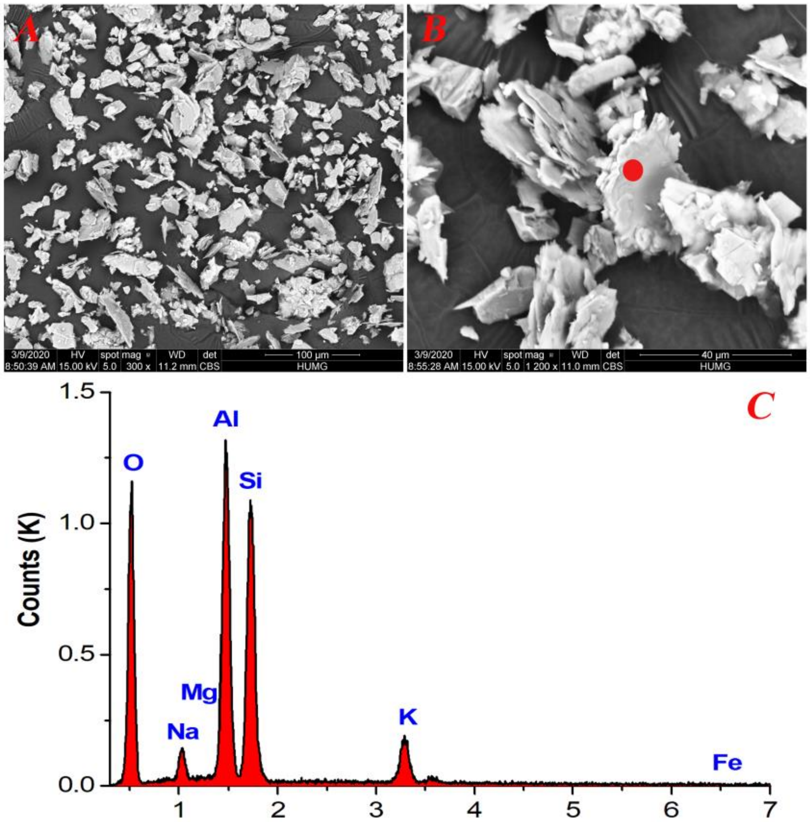

Figure 5. SEM-EDS images of the Son Binh fine sericite 1.
A. At a magnification of 300x; B. At a magnification of 1200x. C. EDS spectrum of sericite.

example, the content of Al_2O_3 ranges from 21.68% to 30.63%, with an average of 24.98%. K_2O contents are from 5.01% to 5.83%, with an average of 5.44%. Thus, it can be seen that the Son Binh fine sericite 1 can meet quality standards as raw materials for paint, polymer, and cosmetic production.

5. Conclusions

In conclusion, in order to assess the quality of Son Binh raw and fine sericite ores, samples were taken from the typical outcrop in Son Binh sericite deposit, Ha Tinh province, and from the Son Binh mineral processing plant. Analysis methods of XRD, XRF, SEM-EDS, ICP-MS, and AAS were used to characterize these sericites. The analytical results indicate that the Son Binh raw sericite ore belongs to a mineral group of sericite - quartz. Single sericite mineral has high purity. Non-metallic mineral compositions are mainly quartz, sericite, and pyrophyllite. There are also a number of other minerals with a small content of kaolinite, chloride, and goethite. Son Binh sericite minerals have a fairly fine grain size, with the grain size < 20 μm, about 60%. Harmful metal elements (Cu, As, and Hg) have quite strong linear relationships with the correlation coefficien ts of 0.83, 0.79, and 0.48. These metal elements exist in different mineral particles or in small solution particles. An effective mineral processing was set up with many technological solutions such as selective grinding, gravity separation, flotation, and chemical processing to increase the quality of Son Binh sericite ore. The fine sericites after mineral processing have good quality. The sizes of the fine sericites are fairly uniform and small, with an average size of about 10 mm. Contents of harmful metal elements in the fine sericite are lower than those in quality regulations (0.34% Pb, 1.8% As and 0.16% Cd). Chemical compositions of the fine sericite samples had a significant change. Thus, it can be seen that the Son Binh sericite after mineral processing completely meets quality standards for fields of paint, polymer, and cosmetic production.

References

Altaner S.P. and Vergo N., 1988. Sericite from the Silverton caldera Colorado: Discussion. *American Mineralogist* 73, 1472-1474.

Ciullo P.A. (Ed.), 1996. *Industrial minerals and their uses: a handbook and formulary*. Noyes Publications.

Davis J.C. (Ed.), 2002. *Statistics and data analysis in geology*. New York ,

Sreenivas B., Roy A.B., Srinivasan R., 2001. Geochemistry of sericite deposits at the base of the Paleoproterozoic Aravalli Supergroup, Rajasthan, India: Evidence for metamorphosed and metasomatised Precambrian Paleosol. *Proc. Indian Acad. Sci. (Earth Planet. Sci.)*, 110, 1, 39-61.

Takahisa Y. and Yujin I., 1989. Ferrierite in a hydrothermal alteration zone around the murakami sericite deposit. *Journal of the Clay Science Society of Japan (in Japanese)* 29, 179-186.

Nguyen Van Hanh, Dao Duy Anh, Nguyen Thi Thanh Thao, 2010. Evaluating quality and ability of mineral processing and applications of Son Binh sericite ore', *Journal of Geology Series A*, 38-44.

Tran Trong Hue and Kieu Quy Nam, 2006. Sericite mineralization in Viet Nam and its economic significance. *Journal of Geology Series B*, 22, 61-69.

Nguyen Van Pho et al., 2014. Project: *Research on the mineral processing of sericite ore in Huong Son region, Ha Tinh for paint and polymer industry*. Project in Vietnamese Ministry of Industry and Trade.

Nguyen Thi Thanh Thao, 2016. PhD Thesis - *Characteristics of sericite mineralization in Dong Trau formation in Son Binh area, Ha Tinh and its possibility of using*. Hanoi University of Mining and Geology.

Nguyen Thi Thanh Thao and Ngo Xuan Thanh, 2014. Characteristics of sericite mineralization in Sơn Bình area, Hương Sơn district, Hà Tĩnh Province. its relation with regional tectono-magmatic phases. *Journal of Geology Series A*, 340, 37-45.

Pham Tich Xuan, Nguyen Van Pho, Doan Thu Tra, Hoang Tuyet Nga, Pham Thanh Dang, Nguyen Thi Lien, Nguyen Thi Thanh Thao, 2013. Sericite Ore Prospects in Huong Son - Ky Anh region (Ha Tinh Province). *Vietnam journal of earth sciences* 35 (2), 97-106.

Pham Tich Xuan et al., 2014. *Investigating and evaluating the potential of sericite minerals in the North Central region, proposing technology for exploitation and mineral processing to improve their economic efficiency*. Project in Institute of Geological Sciences - Vietnam Academy of Science and Technology.