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The Mineral Distribution of Hsiang-Yang Mica, Taiwan

向陽雲母之礦物分布研究

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Abstract

The Hsiang-Yang mica deposit, which belongs to the sericite-pyrophyllite-quartz schist, is located at Litao Village of Taitung County, Taiwan, R.O.C. The total reserve is estimated to be about 30 million tons. Hsiang-Yang mica is one of the most economically valuable industrial minerals of R.O.C. The mineral distributions of sericite and pyrophyllite in various size ranges of the ore were investigated. From the results of contact angle measurement, XRD analysis, SEM and the chemical analysis, it is found that the average sericite content in the mica powder is about 60% and pyrophyllite is about 40%. In the >20 μm size range, the sericite content is about 18%, while pyrophyllite is about 82%. The concentration of sericite increases with decreasing particle size. In the size range of <10 μm, the sericite content is 73%. On the other hand, pyrophyllite content is 70% for sizes >10 μm.

Key words: Ore mineralogy, sericite, pyrophyllite, mineral distribution.

摘　要

向陽雲母礦位於中華民國臺灣省臺東縣海端鄉利稻村，全礦賦存量估計約有 3,000 萬噸，礦種屬絹雲母－葉蠟石－石英片岩。以過去十年之平均產量，向陽雲母礦之規模位居世界第十，是中華民國最具經濟價值之工業礦物之一。本研究探討絹雲母及葉蠟石在不同粒徑範圍之分布，由接觸角量測、X 光繞射分析、電子顯微鏡（SEM）及化學分析之結果顯示：雲母粉中絹雲母含量約為 60%，葉蠟石約為 40%；在粒徑>20 μm 之範圍，絹雲母含量為 18%，而葉蠟石為 82%，絹雲母含量隨粒徑之減小而增加，在粒徑<10 μm 之範圍，絹雲母含量達 73%，另一方面，在粒徑>10 μm 之範圍，葉蠟石含量達 70%。

關鍵詞：礦石礦物學，絹雲母，葉蠟石，礦物分布。

1. Introduction

The Hsiang-Yang mica deposit is located at the northwest of Litao Village of Taitung County, Taiwan, R.O.C. (Figure 1) It is the only powder mica producing mine in Taiwan. The total reserve is estimated to be about 30 million tons. The ore type of this mine belongs to the sericite-pyrophyllite-quartz schist, which is associated with minor minerals of pyrite, chlorite and calcite (Chen, 1984; Bureau of Mining Affairs, 1995). The ore, which is mined by open pit, is hydraulically classified to remove heavy

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and coarse gangue minerals. The final mica powder product contains about 60% of sericite and 40% of pyrophyllite, with minute amount of chlorite. The present production of Hsiang-Yang mica is about 3,000 tons per year. It is one of the most economically valuable industrial minerals of R.O.C. (Mining Department, MOEA, 1995; Tan and Wei, 1997).

Because of the excellent properties of mica in anti-UV, static-conductance, heat endurance, insulation, chemical stability, physical flexibility, it is used as filler in the electrical insulation plate, fire-resistance material, paint, plastic fillers, etc. Also because of its characteristic whiteness, greasiness and silky gloss, fine mica powders are used in the paint, pigment, medicine, cosmetics (Miller, 2009; Madhukar and Srivastava, 1995). Most of Hsiang-Yang mica at present is used in the traditional industries.

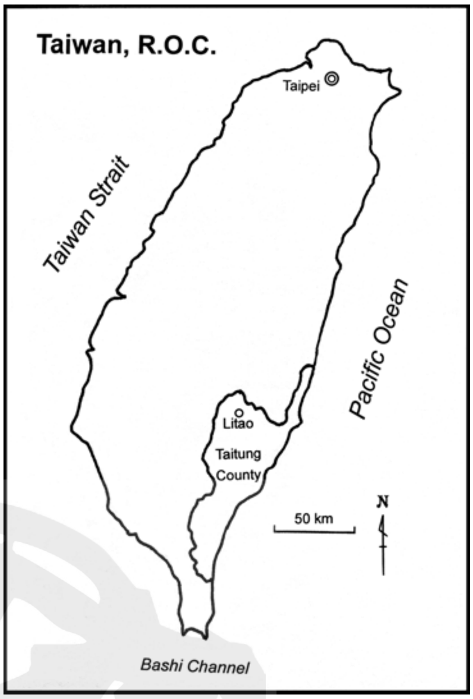


Figure 1: The location of Hsiang-Yang mica deposit.

Sericite is a layered silicate mineral, its chemical composition and crystal structure are the same as muscovite, [$KAl_2(AlSi_3)O_{10}(OH)_2$], only extremely fine-grained. Pyrophyllite is also a layered silicate mineral [$Al_2Si_4O_{10}(OH)_2$] (Cornelis and Hurlbut, Jr, 1999). Because of the difference in physical and chemical properties of these two minerals, their distributions with size should be different.

This study is to investigate the distribution of sericite and pyrophyllite in various size ranges so as to obtain fundamental information of Hsiang-Yang mica deposit. The samples used in this study were the commercialized mica powder supplied by Sunshine Mining Co. Samples were first classified by sedimentation into several size ranges. The relative mineral composition change in different size ranges was represented by contact angle value, XRD peak ratio and chemical analysis.

2. Experimental

(1)Materials

The mica powder samples were supplied by Sunshine Mining Co., denoted as water-processed mica. The density is 2.76 g/cm^3. The particles are all passing 400 mesh sieve. The size distribution measured using an Andreassen pipette is shown in Figure 2. It can be shown that the size distribution fits the Gates-Gaudin-Schuhmann function, i.e. $P = (x/x_{max})^k$, where P is the cumulative mass fraction of particles finer than size x; x_{max} is the intercept of the curve on a double-logarithmic plot at P=1; k is the slope of the curve or the distribution modulus. It can be shown from Figure 2 that k=0.87, x_{max}=11 μm and d_{50}=5 μm.

The XRD analysis was performed using a Siemens D500 X-ray powder diffraction analyzer. The pattern is shown in Figure 3. It can be seen that the major mineral constituents are sericite and pyrophyllite, with minor amount of chlorite. The sericite content in the mica powder is calculated from the analyses of K^+, Na^+, which are shown in Table 1. Assuming the sericite is composed of both potassium and sodium mica, it can be calculated that potassium mica content is about 51%, and sodium mica about 11%. Total sericite therefore is estimated to be about 62% and pyrophyllite to be about 38%, if neglecting chlorite.

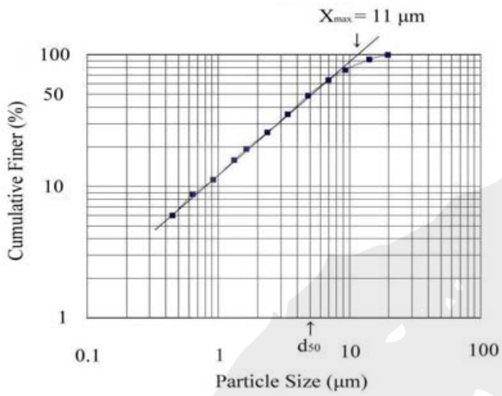


Figure 2: Size distribution of water-processed mica powder (Andreassen pipette conditions: solids 1 %, pH 6.3).

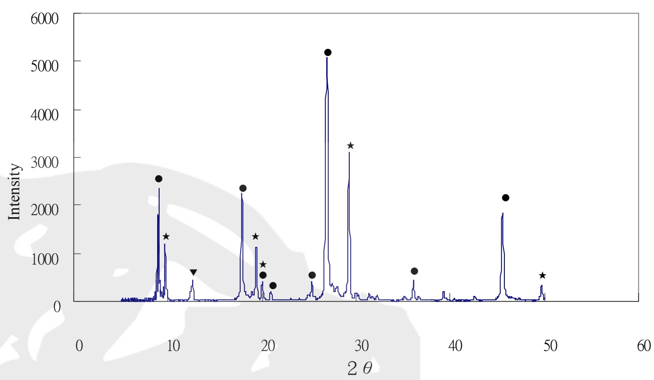


Figure 3: The XRD patterns of water-processed mica powders.

Table 1: K^+ and Na^+ analyses of water-processed mica with calculated sericite content.

	K^+ (mg/g)	Content of K-mica (%)	Na^+ (mg/g)	Content of Na-mica (%)	Content of sericite (%)
K-mica	98.17		0		
Na-mica	0		60.16		
Water-processed mica	50.05	51.0	6.79	11.3	62.3
Formula for calculation of sericite content	Content of K-mica(%) = K^+(mg/g)/0.9817 Content of Na-mica(%) = Na^+(mg/g)/0.6016 Sericite (%)= K-mica + Na-mica				
Remarks	1. K-mica, $KAl_2(AlSi_3)O_{10}(OH)_2$ = 398.3 2. Na-mica, $NaAl_2(AlSi_3)O_{10}(OH)_2$ = 382.3 3. Pyrophyllite, $Al_2Si_4O_{10}(OH)_2$ = 360.3				

(2)Procedures

A. Classification

Mica samples were classified by sedimentation method into >20 μm, 20-15 μm, 15-10 μm, 10-7.5 μm, 7.5-5 μm, 5-2.5 μm, 2.5-1μm and <1 μm eight size intervals. To avoid the fines mixing into the coarse, e.g. <15 μm particles into 20-15 μm interval, repeated sedimentation separations were performed as many as 10 times. Since mica particles are disc-like, these sizes presented are equivalent spherical diameters. The classified samples were then subjected to the following semi-quantitative and quantitative analyses to determine the mineral distributions in different size intervals.

B. Contact angle measurement

The classified mica powders were pressed into discs, under the pressure of 120 MPa, a drop of de-ionized water was laid on the disc, and the contact angle was measured immediately and analyzed by a Software of SCA 20 (Data Physics GmbH, Germany).

C. XRD

The powder was pressed uniformly on the glass sample plate, a Siemens D500 XRD analyzer was used to identify the mineral phase. The operation conditions were: 40 kV/40 mA, Cu-target ($\lambda_{K\alpha 1}$=1.5406 Å), scanning speed 0.04°/sec. The relative change of characteristic diffraction peaks of sericite and pyrophyllite was examined to estimate the mineral distributions.

D. Chemical analysis

About 0.1 g of sample was weighed and mixed with 17 ml of an acid mixture (nitric acid: hydrochloric acid: fluoric acid=3:9:5). The sample was put in a microwave digester (Ethos D, Milestone Inc., Italy), and digested at 150°C for about 30 min to become complete solution. The solution was diluted to proper ratio, and the concentrations of K^+, Na^+ were analyzed with an Atomic absorption spectrometer (Perkin Elmer AAnalyst100). The wavelengths used were λ=766.5 Å for K^+ and λ=330.2 Å for Na^+.

3. Results and discussion

(1)Classification

The weight fraction of each size interval by sedimentation classification and the data obtained from the size distribution measurement are listed in Table 2. It can be seen that the classification was performed quite accurately and the obtained samples can be used for semi-quantitative and quantitative analyses.

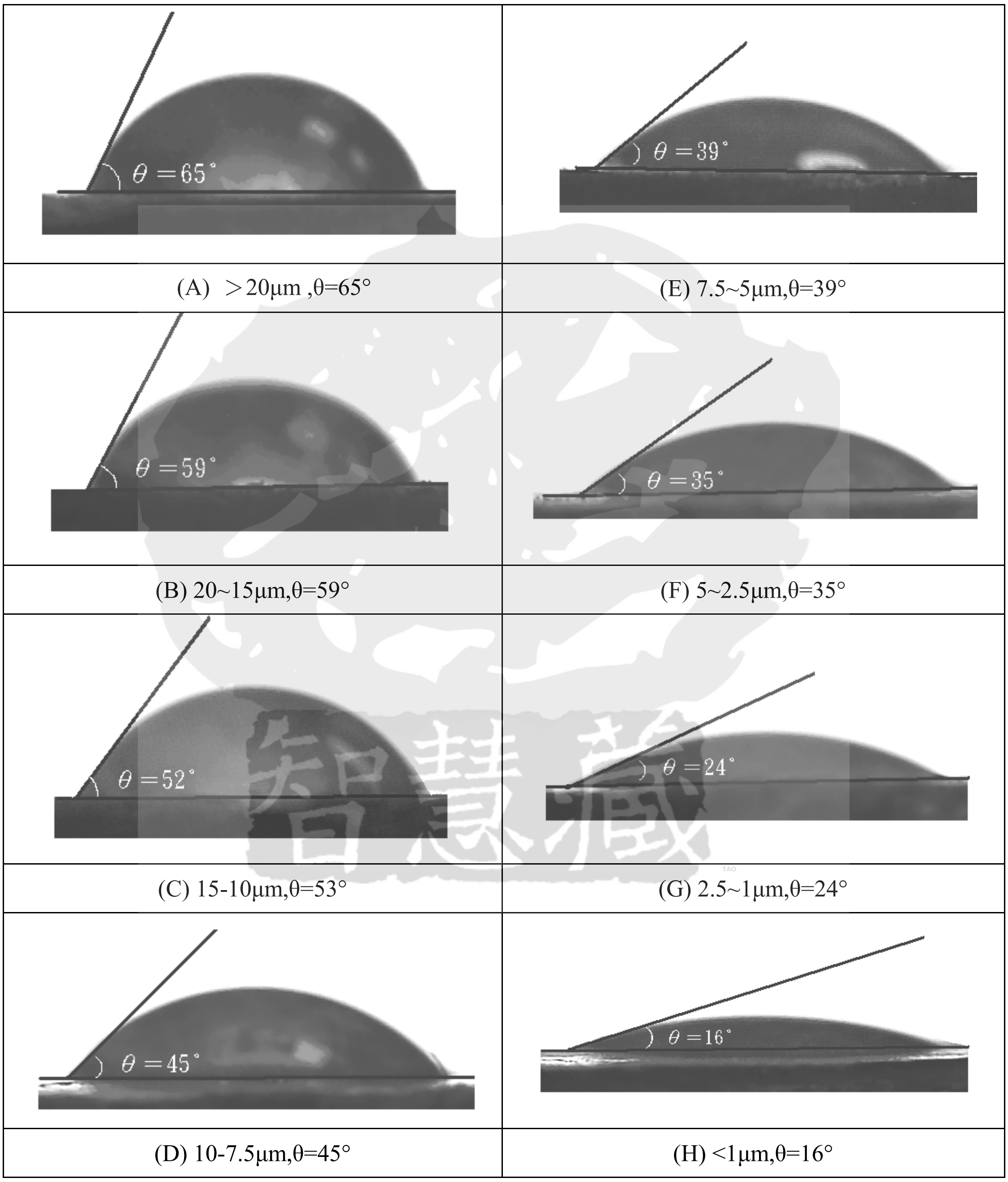
Table 2: Weight fraction of each size interval (data from sedimentation classification and Andreassen pipette).

Size interval (μm)	Weight fraction	
	Sedimentation Classification (%)	Andreassen Pipette (%)
>20	5.7	6
20-15	3.5	5
15-10	10.0	10
10-7.5	10.1	11
7.5-5	18.2	19
5-2.5	26.0	24
2.5-1	14.5	13
<1	12.0	12
Total	100.0	100

(2)Mineral distribution analysis

A. Contact angle

The surface of sericite carries negative electric charges because of lattice cation replacement (Al^{3+} replaces Si^{4+}) and is polar, while pyrophyllite is non-polar. Hence sericite surface is more hydrophilic than pyrophyllite. Figure 4 are pictures showing drops of de-ionized water resting on the discs prepared from classified mica powders. The contact angle values are summarized in Table 3. From the results, it can be seen that the mineral distribution of these two minerals varies with the size. The contact angle for the sample of >20 μm is 65°, which is the largest, and decreases with size to 16° for the sample of <1 μm. These results provide evidences, at least semi-quantitatively, that sericite is concentrated in the fine size ranges and pyrophyllite concentrated in the coarse size ranges.



(A) ＞20μm ,θ=65°
(E) 7.5~5μm,θ=39°
(B) 20~15μm,θ=59°
(F) 5~2.5μm,θ=35°
(C) 15-10μm,θ=53°
(G) 2.5~1μm,θ=24°
(D) 10-7.5μm,θ=45°
(H) <1μm,θ=16°

Figure 4: The contact angle measurement of water drop on classified mica surfaces.

Table 3: The contact angles of classified mica powders.

Sample size (μm)	>20	20-15	15-10	10-7.5	7.5-5	5-2.5	2.5-1	<1
Contact angle +	65°	59°	53°	45°	39°	35°	24°	16°

B. XRD analysis

The XRD patterns of the water-processed and classified mica powders are shown in Figure 5. It is seen that the characteristic peak heights of sericite (006), (004) and (002) planes and pyrophyllite (003), (002) and (001) planes are varying with size. Generally sericite peak height increases and pyrophyllite peak height decreases with decreasing size. Since inner standard was not used in these samples, only peak heights ratio of sericite and pyrophyllite planes were compared and are shown in Figure 6. It can be seen that generally the sericite (002), (004), (006) to pyrophyllite (001), (002), (003) peak ratios increases with decreasing sizes. The XRD peak height is both a function of crystal size and crystallinity, actually it is not proper to be used for quantitative analysis. However, from the peak ratio change, a trend that sericite is concentrated in the fine and pyrophyllite in the coarse size ranges still can be shown.

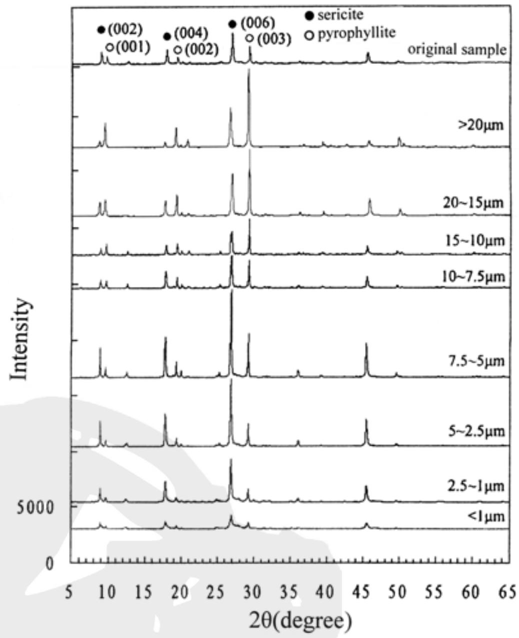


Figure 5: The XRD patterns of classified mica powders.

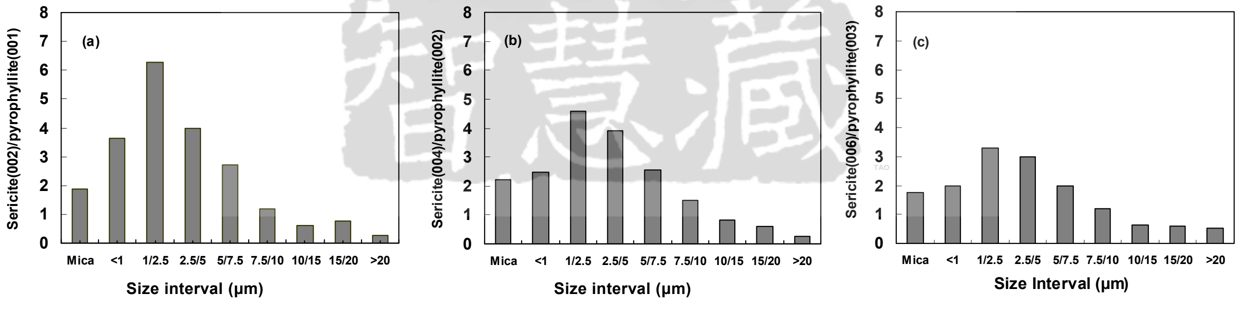
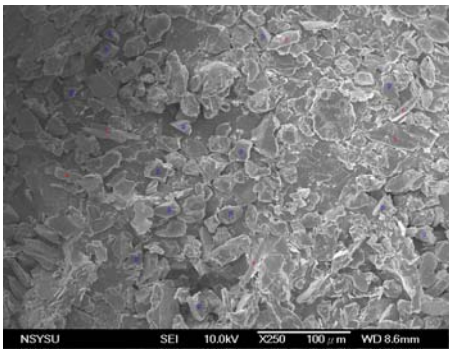


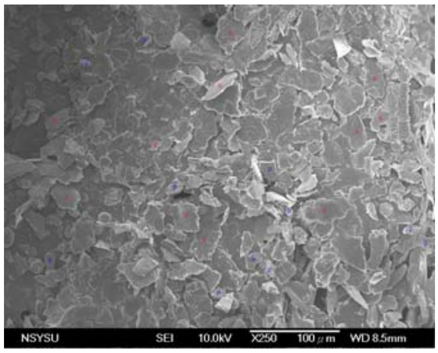
Figure 6: The XRD peak ratios of sericite and pyrophyllite of different sizes: (a)S(002)/P(001); (b) S(004)/P(002); (c) S(006)/P(004).

C. SEM micrographs

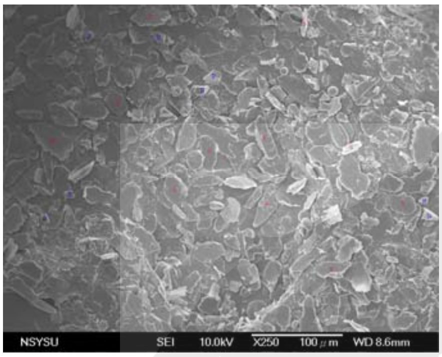
Figure 7 shows the SEM micrographs of the classified mica. It can be seen that the massive pyrophyllite particles are abundant in the coarse size samples; as the particle size decreases, the sheet-like sericite particles are getting more popular. These pictures match quite consistently with the contact angle and XRD results.



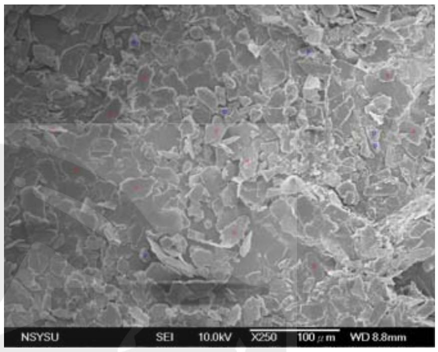
(a) >20 μm (magnification: 250)



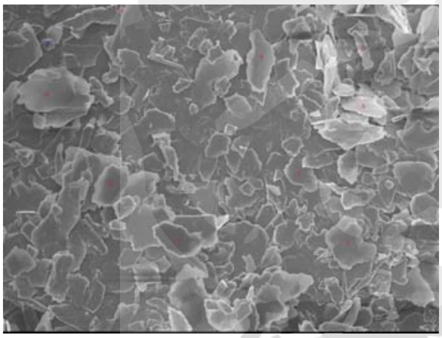
(b) 20-15 μm (magnification: 250)



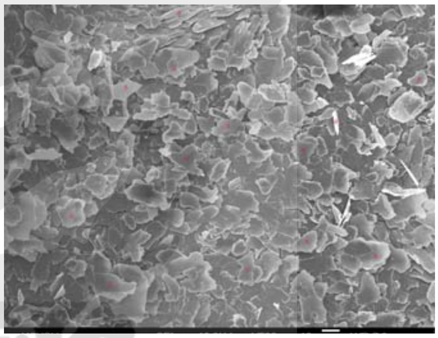
(c) 15-10 μm (magnification: 250)



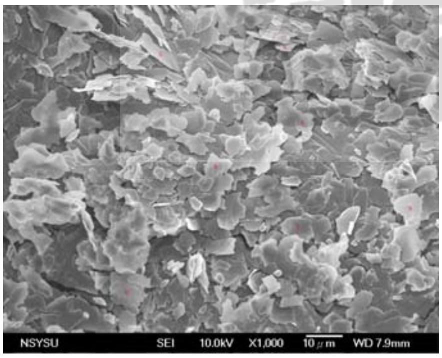
(d) 10-7.5 μm (magnification: 250)



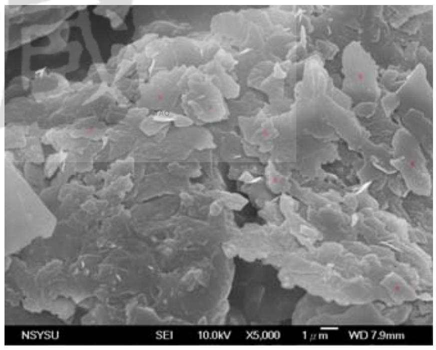
(e) 7.5-5 μm (magnification: 500)



(f) 5-2.5 μm (magnification: 500)



(g) 2.5-1μm (magnification: 1,000)



(h) ＜1 μm (magnification: 5,000)

Figure 7: The SEM micrographs of mica samples of different sizes.

D. Chemical analysis

If sericite is composed of potassium and sodium mica, then the concentrations of K^+ and Na^+ can be used to estimate the content of sericite. The rest part would be the pyrophyllite, assuming that the chlorite is negligible. The chemical analysis thus can be a means most close to the quantitative mineral analysis. The data of chemical analysis can also be used to check the reliability and precision of other semi-quantitative analyses used in this study. The results are listed in Table 4. It can be seen that the content of sericite increases with the decreasing of particle size. The maximum sericite content occurs at the size interval of 2.5-1 μm, about 79%. Generally, when particle size is finer than 10 μm, the sericite content becomes higher than 70%. Inversely, for particles larger than 10 μm, the pyrophyllite content is more than 70% (deducted by 29.5% sericite). Thus a classification process at 10 μm should be able to roughly concentrate both sericite and pyrophyllite.

The data of sericite content obtained from chemical analysis and XRD peak ratio are summarized in Figure 8. It can be seen that the XRD peak ratio correlated quite well with the sericite content. Thus XRD could be used as a semi-quantitative analysis tool. Similarly, the sericite content and contact angle is summarized in Figure 9. The correlation also seems to be quite good.

Table 4: K^+ and Na^+ analyses of classified mica with calculated sericite content.

Weight distribution (%)	Size interval (μm)	K^+ (mg/g)	Na^+ (mg/g)	Content of sericite (%)	Cumulative sericite from coarse (%)	Cumulative sericite from fine (%)
		98.16 (K-mica)	0			
		0	60.15 (Na-mica)			
5.7	>20	13.53	2.37	17.7	17.7	65.2
3.5	20-15	19.24	2.74	24.2	20.2	68.0
10.0	15-10	30.42	4.22	38.0	29.5	69.7
10.1	10-7.5	49.44	5.81	60.0	40.0	73.7
18.2	7.5-5	61.83	6.88	74.4	53.2	75.6
26.0	5-2.5	61.80	8.16	76.5	61.4	76.0
14.5	2.5-1	64.13	8.34	79.2	64.4	75.6
12.0	<1	54.03	9.74	71.2	65.2	71.2
Formula for calculation of sericite content		Content of K-mica (%) = K^+ (mg/g) / 0.9817 Content of Na-mica (%) = Na^+ (mg/g) / 0.6016 Sericite (%) = K-mica + Na-mica				

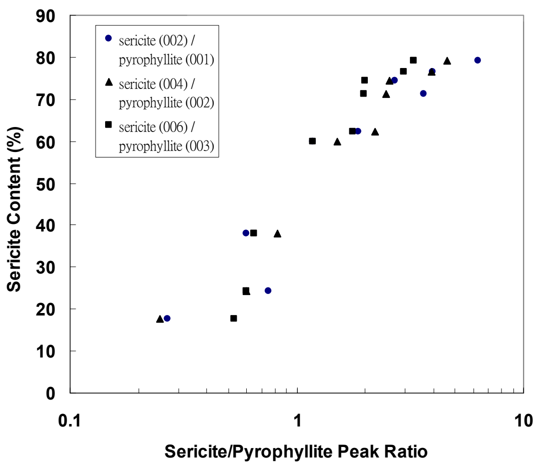


Figure 8: Correlation between the sericite content and sericite /pyrophyllite XRD peak ratios.

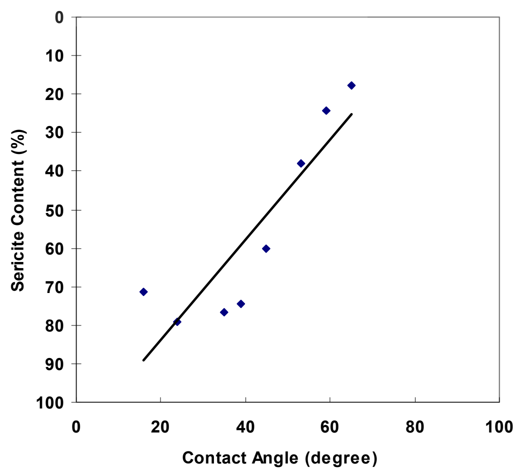


Figure 9: Correlation between the sericite content and contact angles.

4. Conclusions

Hsiang-Yang mica is composed of sericite and pyrophyllite with minute amount of chlorite. The size distribution fits the Gates-Gaudin-Schuhmann distribution function, with distribution modulus, k=0.87, size modulus x_{max}=11 μm and d_{50}= 5 μm. From contact angle measurement and XRD analysis it can be shown that sericite is concentrated in the fine size ranges and pyrophyllite concentrated in the coarse size ranges. SEM micrographs show that the pyrophyllite present as massive particles, abundant in the coarse size ranges; the sericite as sheet-like particles, concentrated in fine size ranges. The chemical analysis is the most reliable and precise way to estimate sericite content. The results of chemical analysis, contact angle and XRD show that contact angle and XRD can be semi-quantitative analysis tools. The average sericite content of the water-processed mica is about 60% and pyrophyllite is about 40%. The sericite in the >20 μm range is about 18%, while pyrophyllite is about 82%. The concentration of sericite increases with decreasing size. The maximum is about 80% in the size range of 2.5-1 μm. In the size range of <10 μm, the sericite content is 73%. On the other hand, pyrophyllite content is 70% for sizes >10 μm. A classification process at 10 μm should be able to roughly concentrate both sericite and pyrophyllite.

5. Acknowledgements

Sunshine Mining Co., which provided mica samples for this study, is greatly appreciated.

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