February 2006 Volume 1 Issue 1

Environmental Science

Trade Science Inc.

An Indian Journal

Current Research Paper

ESAIJ, 1(1), 2006 [16-23]

Mineralogyc And Physico-Chemical Characteristics Of Bentonite Clay From Sabah Malaysia

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Received: 4th December, 2005
Accepted: 12th February, 2006

Web Publication Date : 4th March, 2006

ABSTRACT

This paper presents the results of laboratory work on mineralogy, physico-chemical characteristics the bentonite clay from two areas of Sabah, Malaysia, namely Andrassy and Mansuli. A standard wyoming bentonite had been used as a potential comparison. This study included mineralogical, chemical composition, cation exchange composition, specific surface area and atterberg limit. The results from mineralogy investigation showed that Sabah bentonite less montmorillonite mineral content than wyoming. Based on chemical composition, Sabah bentonite has ferrous iron content higher than wyoming bentonite. Cation exchange capacity (CEC) and specific surface area values of Sabah bentonite is lower than wyoming bentonite while from atterbeg limit Sabah bentonite is closed to the Ca-montmorillonite.

KEYWORDS

Montmorillonite;
Mineralogy;
Physical;
Chemical;
Exchangeable cation;
Specific surface area;
Atterberg limit.

INTRODUCTION

Bentonite is a member of general clay mineral groups and consists of smectite clay and impurities such gravel, shale, limestone, quartz and other minor minerals[1]. Bentonite deposits are distributed only in tertiary formations, especially in the green tuff regions of Miocene age[2], which formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash and it often contains various proportions of accessory crystal grains that were originally phenolcrysts in the volcanic glass[1]. These are feldspar (commonly orthoclase and oligoclase), biotite, quartz, pyroxene, zircon and various typical of volcanic rocks. Bentonite crystals have flat thin sheet morphology. The shape of bentonite can be up to 1,000 nm in the largest dimension. However, a side view of the crystal reveals a uniform size of 0.92 nm thicknesses. The result of this morphology is an extremely large surface area of about 800m^2/g[3]. It has found application in various industries, such as drilling mud material, cement additives, ceramic material, foundry molding and etc. The effect of the bentonite is to slow the progress of water through the soil or rocks. When bentonite mixed with water, it will swell till 40 Å.

It was reported that the finding of bentonite resources in several areas of Sabah[4] such as in Segama, Sepagaya, Mansuli and Andrassy. In general, the indicated reserve is about 5.3 million tones in Segama, 1.9 million tones in Sepagaya, 1.5 million tones in Mansuli and 3.6 million tones in Andrassy[5]. Most of the bentonite occurrences in Mansuli were taken mainly in area underlain by the Ayer Formation, which collectively form the Segama Group and is interpreted to be Miocene in age[5]. The total coverage area of Mansuli bentonite resources is 12 km^2, with layer thickness average of 1.64 m. The bentonite occurrences in Andrassy area is underlain mainly by the high level of alluvium and volcanic rock, and occur in a bed underlying by Pleistocene to Holocene in age. The total coverage area of Andrassy bentonite resources is 25 km^2, with the bentonite layer thickness average of 2.19 m[6]. Because of promising economic potentiality of the material and the absence of a solid knowledge of the clay properties, it was decided to undertake a study with the objective to determine the mineralogical, physical and chemical properties of Sabah bentonite. With no doubt that the production of Sabah bentonite will generate an alternate income, which can increase the gross domestic product (GDP) of Malaysia.

EXPERIMENTAL

1. Field sampling

In this study, wyoming bentonite (WY-BEN) sample that used as reference bentonite was import from the United State. The Sabah samples were collected from two areas, the Andrassy area in Tawau and Mansuli area in Lahad Datu. The location of

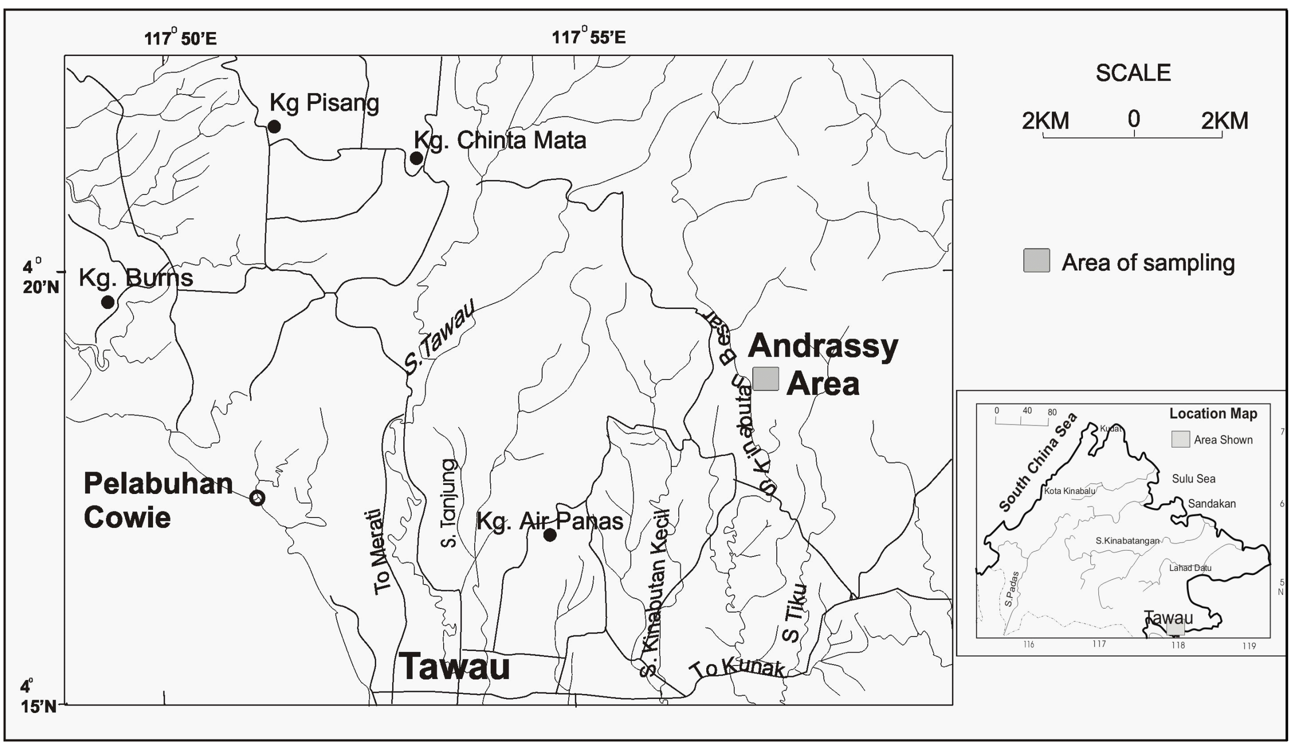

Figure 1: Location of SA5 sampling in Andrassy area of Tawau.

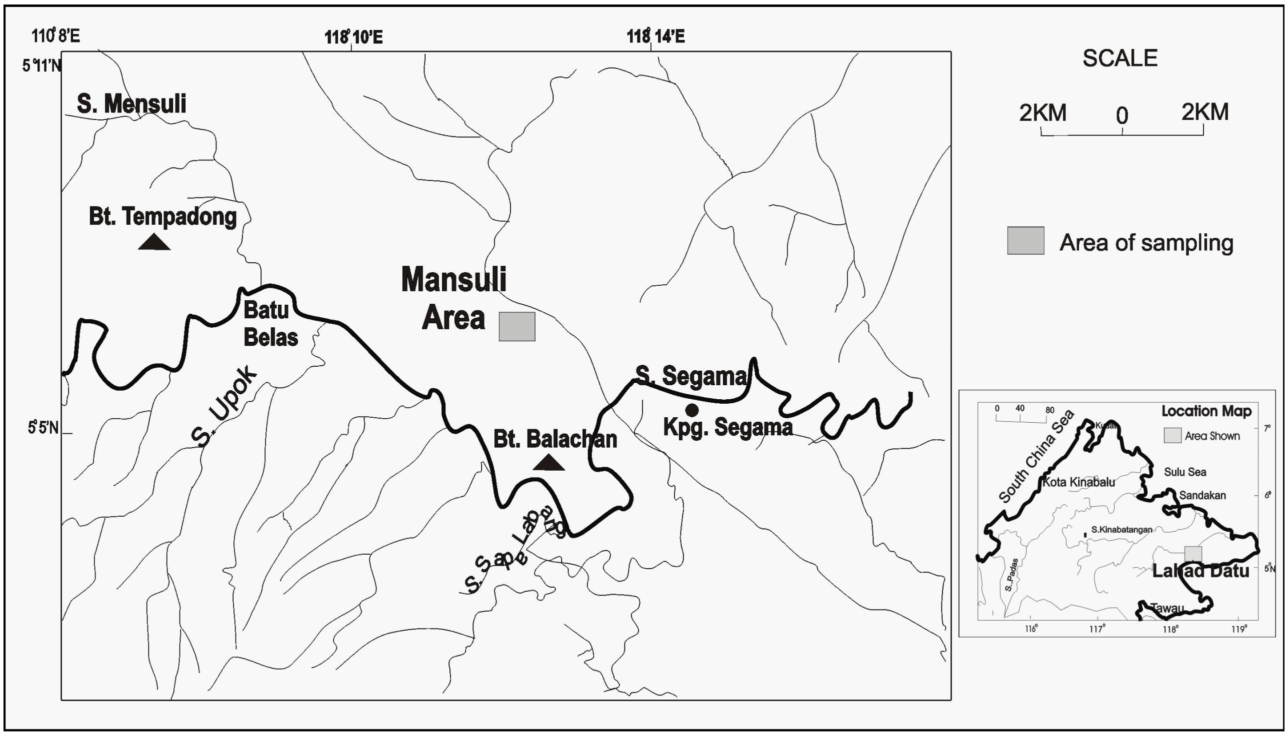

Figure 2: Location of M4 sampling in Mansuli area of Lahad Datu

Andrassy samples is N 4°18.97' - E 117° 57.37' and the Mansuli location is N 5° 7.35' - E 118° 12.03' as shown in figure 1 and 2, respectively. The depth of sampling is 0.5 meter for Andrassy (SA5) and 0.3 meter for Mansuli (M4).

2. Mineralogy, physical and chemical properties determination

In the industry, the most accurate and satisfactory procedure or method to identify the mineral fraction of a bentonite samples is by means of X-ray diffraction (XRD). Analysis of powders by XRD requires extremely fine-grained to achieve good signal-to noise ration, avoid fluctuation in intensity, avoid spottiness and minimize preferred orientation. Reduction of powders to fine particles also insures enough particle participation in the diffraction process. The recommended size range is around 1 to 5 μm[7], especially if quantification of various phases is desired. Chemical property of bentonite is cation exchange capacity (CEC) and specific surface area (S_s). Cation exchange capacity (CEC) of the samples was determined by a methylene blue absorption technique, while specific surface area was determined using a technique by Santamarina[8]. In addition, the chemical composition of bentonite will be tested by EDX Philip Series-40 instrument. This equipment can calculated quantitatively of bentonite element based on the emission of electron in it's orbital. Physical properties determinations include the Atterberg limit such as liquid limit (LL), plastic limit (PL) and plasticity index (PI). The standard testing method for liquid and plastic limit according to ASTM D4318-00[9]. Liquid limit and plastic limit also refer as Atterberg limit, which depending on the moisture content of sample.

RESULTS AND DISCUSSIONS

As shown in TABLE 1 and 2, the Andrassy sample, SA5-1 and SA5-7 seem to have montmoril-

TABLE 1: Quantitative analysis of Andrassy and Mansuli samples.

	Reference Bentonite	Andrassy sample				Mansuli Sample M4
		SA5 -1	SA5 -3	SA5 -4	SA5 -7	
Montmorillonite content(% volume)	90.96	11.99	9.35	9.30	14.80	8.44

TABLE 2: Semi-quantitative analysis of Andrassy and Mansuli samples.

Mineral Composition	Reference Bentonite	Raw Bentonite Samples				
		SA5-1	SA5-3	SA5-4	SA5-7	M4
Montmorillonite ($Na_{0.30}$ ($Al_{1.55}$ $Fe^{3+}_{0.20}$ $Fe^{2+}_{0.01}$ $Mg_{0.24}$) ($Si_{3.96}$ $Al_{0.04}$) O_{10} $(OH)_2$	****	**	*	*	**	*
Quartz (SiO_2)	nd	*	*	*	**	***
Kaolinite ((Al_2 Si_2 O_5 $(OH)_4$)	nd	*	*	*	nd	tr
Illite ((K, H_3 O) (Al, Mg,Fe)$_2$ (Si,Al)$_4$$O_{10}$)	nd	**	**	**	**	*
Others	* Feldspar (K Al Si_3 O_8)	* feldspar	tr feldspar	* feldspar	nd	* feldspar

Note : **** : dominant; *** : major; ** : : minor; *; appreciable, tr : traces, nd: not detected

lonite mineral as theirs minor component while the M4 (Mansuli) samples have montmorillonite mineral as theirs appreciable component. The reference bentonite sample has the highest montmorilonite content with 90.96 % of volume fraction. The Andrassy sample also contains feldspare in a small amount, which is identical to the reference bentonite except for sample SA5-7. However, the Andrassy sample also contains kaolinite and illite in a small quantity, which is slightly higher than the reference bentonite. Therefore, it is clear that the occurrence of bentonite in Andrassy area of Tawau consists quartz, kaolinite, illite and feldspar as an impurities mineral. For M4 sample from Mansuli area, the situation is even worse because the predominant mineral for this sample is quartz instead of montmorillonite mineral. The montmorillonite is just appears as minor mineral with the presence of kaolinite, illite and feldspar in small quantity. This showed that the Mansuli deposits are located between the mixed layers, which consist of Na-bentonite and quartz layers. In general, mineral composition of samples cannot be altered since it is depends on the origin of bentonite it self. Detailed XRD results are shown figure 3, 4 and 5, respectively. Generally, the range of liquid limit (LL) for bentonite is around 100 % to 800 %[10]; with 700% for the reference bentonite. For Sabah bentonite samples, the liquid limit values are below the bentonite range, i.e. ranging from 63.35 to 148 as compared 700% for reference bentonite as shown in

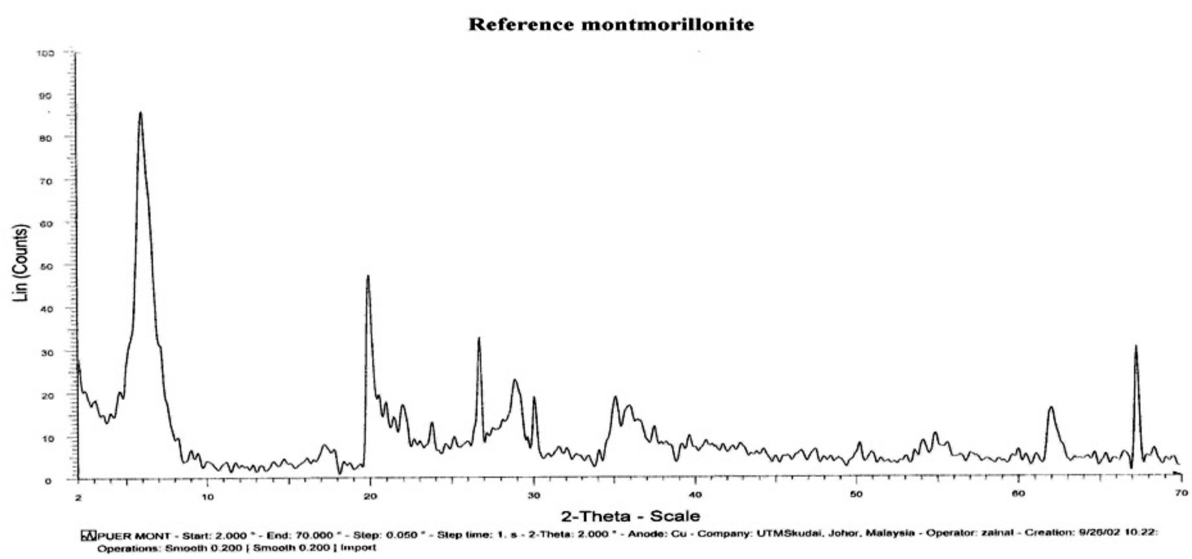

Figure 3: XRD pattern for reference bentonite sample

TABLE 3: The Atterberg limit of bentonite samples.

Atterberg Limit	Reference Bentonite	Bentonite Samples				
		SA5-1	SA5-3	SA5-4	SA5-7	M4
Liquid Limit, %	700	122.95	63.35	69	148	81
Plastic limit, %	65	41.73	32.12	32.21	50.1	29.79
Plasticity Index, %	635	81.22	31.23	36.79	97.9	51.21

TABLE 3. The liquid limit of bentonite mainly depends on the moisture or the water adsorption ability, which is depending on its content. Since the SA5-3 sample rich in impurities mineral, therefore its liquid limit is very low.

The plastic limit (PL) of reference bentonite was found as 65%. From TABLE 3, it is clear that SA5-7 sample has the highest plastic limit (PL) followed by SA5-1, SA5-4, SA5-3 and lastly M4 sample. From the order, it is known that the plastic limit has direct relationship with the plasticity of bentonite. SA5-7 sample has the highest plastic limit, therefore the SA5-7 sample is better water adsorption and swelling capability compared to the others sample. Again, M4 sample has the lowest plastic limit value due to high quartz content. Since most fine-grained clay is considered to have plastic characteristic, the mea-

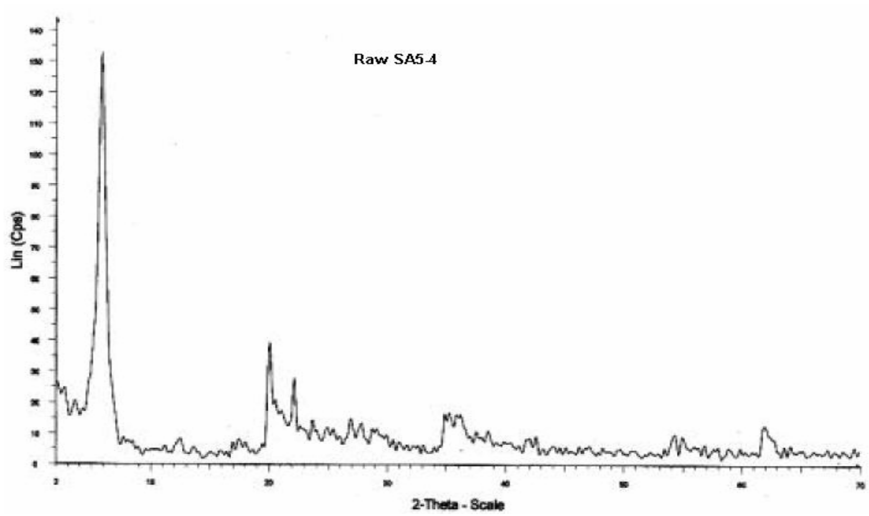

Figure 4: XRD pattern for Andrassy bentonite sample

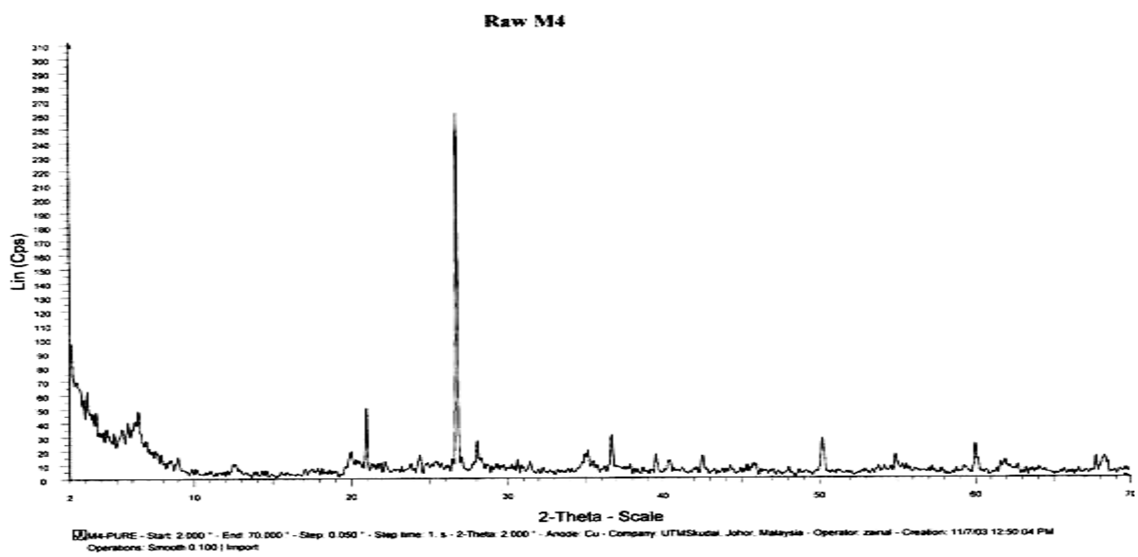

Figure 5: XRD pattern for Mansuli bentonite sample

surement of water content is often employed to determine how good the plasticity of the sample. As an integration of liquid limit and plastic limit, plasticity index means that the bentonite can absorb some amounts of water without changing physical states i.e. the higher the better absorbent capability. For reference bentonite, the plasticity index is 635%; this means the water absorption capability is very good. As for low plasticity index (less than 100 %) of the Andrassy and Mansuli samples, only small amount of water can be absorbed. With refer to plastic limit versus plasticity index graph as shown in figure 6; the SA5-3, SA5-4 and M4 samples fall within the area of plastic kaolin. The SA5-1 and SA5-7 samples can be categorized as calcium bentonite because of their better liquid limit and plasticity index values. The chemical composition of bentonite sample SA5-1, SA5-3, SA5-4, SA5-7 and M4 have been tested and compared to the chemical composition of reference bentonite as shown in TABLE 4. Generally, there are few important chemical elements that related to the chemical structure of bentonite mineral including silica(Si), aluminum(Al), ferum(Fe), magnesium (Mg), sodium(Na) and calcium(Ca). The montmorillonite minerals in bentonite commonly occur in extremely small particle. Theoretically, the

TABLE 4: Chemical composition of Sabah bentonite samples

Chemical element	Chemical composition (% weight)					
	Reference bentonite	SA5-1	SA5-3	SA5-4	SA5-7	M4
O	38.24	36.26	36.77	36.25	40.25	34.41
Na	2.21	0.58	0.42	0.63	1.07	0.93
Mg	2.23	1.58	1.68	1.70	1.82	1.65
Al	11.68	13.50	13.56	14.08	13.45	9.59
Si	35.06	32.82	32.72	33.94	31.11	28.75
P	1.31	1.87	1.82	1.93	1.65	4.31
Cl	0.38	1.13	0.08	0.84	0.31	0.44
K	0.67	1.61	1.18	1.24	1.13	0.45
Ca	1.69	1.62	1.80	1.17	1.45	1.18
Ti	0.44	1.07	1.33	0.71	0.91	0.55
Mn	0.68	0.31	0.75	0.36	0.34	0.26
Fe	5.41	7.65	7.90	7.15	6.52	16.49
Total	100	100	100	100	100	100

composition without the interlayer materials (exchangeable cation and water) is 66.7% Si; 28.3% Al, and 5% H_2O[4]. However, the bentonite always differs from the theoretical formula because of substitutions within the lattice in tetrahedral and octahedral coordination. As shown in TABLE 4, the silicon (Si) content of reference bentonite seem do not satisfy the theoretical formula, so are the Andrassy and Mansuli bentonite samples, which has a lower amount of Si content than suggested by[11]. The Aluminum (Al) content of reference bentonite is 11.68%, which is much lower than the theoretical formula and it shows that the Al had been substituted by ferum (Fe) in octahedral sheet (as high as 5.41%). M4 sample also has the similar situation, with Al content of 9.59% and Fe content of 16.49%. As for the Andrassy sample, the amount of Al content is between 13.45 % to 14.08 %, which are higher than reference bentonite and M4 samples.

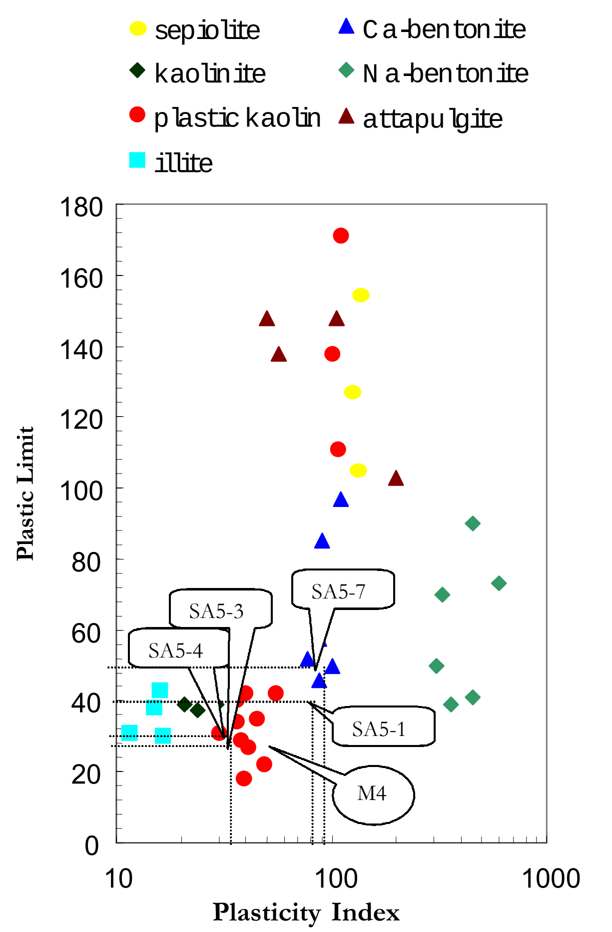

Figure 6: Sabah bentonite plasticity chart

For Andrassy and Mansuli samples, the calcium is the main exchangeable cation instead of sodium. M4 sample had only 1.18 % of Ca while the Andrassy samples have higher contents of Ca, which are 1.62% for SA5-1 and 1.80 % for SA5-3. This means that the Andrassy sample had more chance to have better ion exchange capability than a Mansuli sample. It is clearly seen that the reference bentonite has sodium content higher than the Andrassy and Mansuli bentonite sample with the following order: reference bentonite >SA5-7>M4>SA5-4>SA5-1>SA5-3.

In addition, the calcium content for SA5-3 is higher than other samples with the following order: SA5-3> reference bentonite >SA5-1>SA5-7>M4 > SA5-4. The Al element content of the Andrassy and Mansuli samples generally higher than the reference bentonite. In addition, the appearance of Mangan (Mn) element will not influence the cation exchange reaction or performance of bentonite since it is only considered as impurity in the bentonite. As shown in TABLE 5, we can see that all CEC values of raw Andrassy sample are much higher than Mansuli sample. However, it is still not as good as the reference bentonite. Cation exchange capacity of the reference bentonite was found as 80 meq/100 g due to the high water absorption according to the analysis of Atterberg limit as discussed aboved. CEC is mainly caused by the absorption ability of bentonite. A bentonite which contains mostly sodium montmorillonite, the CEC will be higher since the sodium montmorillonite have better absorption capability when compared to calcium variety. As shown in TABLE 6, clearly seen that the reference bentonite has a specific surface area around 660.37 m^2/g, which is the highest when compared to the Andrassy and Mansuli samples. As proposed by[10], the range of specific surface area for bentonite is within 400 m^2/g and 800 m^2/g. Therefore, high content of montmorillonite mineral for reference bentonite is expected. As we known, the higher value of specific surface area means the bentonite has more space or surface for cation exchange reaction, which is directly proportional to the cation exchange capacity (CEC). The trend of these results is similar to the cation exchange capacity that previously discussed. It is indicated that SA5-1 has a highest specific surface area among the Andrassy and Mansuli samples followed by SA5-7, SA5-4, SA5-3 and M4 samples. SA5-1 sample exhibits better result than others Andrassy and Mansuli samples in specific surface area because of its mineral content. As discussed in mineral content, the Andrassy sample contain higher amount of montmorillonite content than Mansuli. However, it is believed that SA5-1 and SA5-7 samples contain more sodium montmorillonite mineral than other Andrassy samples. It is known that Na-montmorillonite has larger face or planar surface of negatively charged compared to calcium montmorilonite. This surface will attracts more water molecules than calcium bentonite. For M4 sample from Mansuli, only minor amount of Na-montmorillonite is detected and the specific surface area is absolutely lower than other samples.

TABLE 5: CEC of Sabah bentonite samples.

Sample	CEC (meq/100 g)
Reference Bentonite	80
SA5-1	54
SA5-3	39
SA5-4	41
SA5-7	47
M4	24

TABLE 6: Specific surface area of Sabah bentonite samples

Sample	Specific Surface Area (m^2/g)
Reference Bentonite	660.37
SA5-1	435.18
SA5-3	290.78
SA5-4	293.5
SA5-7	317.95
M4	146.7

CONCLUSIONS

From mineralogy, physical and chemical composition analysis, the Andrassy bentonite sample have montmorillonite mineral as their minor component, while the Mansuli bentonite sample have montmorillonite as theirs appreciable component. With refer to plastic limit versus plasticity index graph, SA5-1 and SA-5-7 from Andrassy area is falls close to calcium bentonite, while Mansuli area falls to region of plastic kaolin. The chemical composition analysis proved that the Ca element in Andrassy is higher than Mansuli area. In general CEC and specific surface values of Sabah bentonite still lower than reference bentonite.

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