SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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POTENTIAL COMMERCIAL EVALUATION OF KAOLIN CLAY DEPOSIT FROM DIFFERENT ORIGIN AND GENESIS

By

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of the requirements for the degree of Bachelor of Engineering with Honours
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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertetion entitled **“The Potential Commercial Evaluation of Kaolin Clay Deposit From Different Origin and Genesis”.** I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title for any other examining body or University.

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LIST OF SYMBOLS AND ABBREVIATIONS

BGS	British Geological Survey
EDX	Energy Dispersive X-Ray
DTA	Differential Thermal Analysis
FTIR	Fourier Transform Infrared Spectroscopy
LA 1	Sample of Lenggong
LL	Liquid Limit
LOI	Loss of Ignition
MoR	Modulus of Rupture
PI	Plasticity Index
PL	Plastic Limit
PSA	Particle Size Analysis
SEM	Scanning Electron Microscopy
TA 1	Sample of Trong
TGA	Thermogravimetric Analysis
TR 1	Sample of Tanjung Rambutan
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

PENILAIAN POTENSI KOMERSIAL DEPOSIT LEMPUNG KAOLIN DARI ASAL MULA DAN GENESIS YANG BERBEZA

ABSTRAK

Lempung Lenggong (LA 1), Tanjung Rambutan (TR 1) dan Trong (TA 1), Perak yang mempunyai asal mula dan genesis yang berbeza telah dikaji untuk menilai potensi komersial dalam industri. Lempung Lenggong dan Tanjung Rambutan berasal dari mendapan lempung primer manakala lempung Trong berasal dari mendapan lempung sekunder. Semua lempung dikaji menggunakan Pembelauan Sinar-X(XRD), analisis Thermal Berbeza (DTA) dan analisis Termogravimetri (TGA), analisis Spektrum Inframerah (FTIR), Mikroskop Imbasan Elektron (SEM) dengan Tenaga Serakan Sinar-X (EDX) dan analisis Pendafluor Sinar-X (XRF). Ujian lain yang dijalankan ialah analisis saiz partikel, kandungan kelembapan, indeks plastik, pH dan ujian jasad bakar. Kaolin Lenggong dan Tanjung Rambutan sesuai sesuai digunakan untuk industri seramik kerana mempunyai kandungan silika sebanyak 64.39% dan 56.22%, sebatian besi (Fe_2O_3) <1% dan rutil <1%. Kaolin Tanjung Rambutan juga berpotensi digunakan sebagai pengisi dan penyalut dalam pembuatan kertas dan cat. Namun, saiz partikel lebih halus hendaklah digunakan bagi memperbaiki sifat jasad bakarnya. Peratus kecut bakar semua lempung agak tinggi iaitu >11% tetapi berkadaran dengan peningkatan suhu pembakaran bermula dari 700^{o}C sehingga 1100 ^{o}C. Beberapa sifat lempung Trong memenuhi spesifikasi industri tetapi kandungan sebatian besinya agak tinggi untuk digunakan dalam industri. Salah satu cara memperbaiki kualiti lempung Trong ialah mengurangkan kandungan sebatian besinya dengan kaedah pelarutlesapan asid organik.

POTENTIAL COMMERCIAL EVALUATION OF KAOLIN CLAY FROM DIFFERENT ORIGIN AND GENESIS

ABSTRACT

Clay from Lenggong (LA 1), Tanjung Rambutan (TR 1) and Trong (TA 1), Perak with different origin and genesis were analysed to evaluate their potential commercial for industrial uses. Lenggong and Tanjung Rambutan clay is primary kaolin clay deposit whereas Trong clay is a secondary clay deposit. They were analysed by using X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray (EDX), Differential Thermal Analysis (DTA) / Thermogravimetric Analysis (TGA) and X-ray Fluorescence (XRF) analysis. Other test included particle size analysis, moisture content, plasticity, color, firing test, pH test, and fired body test are also done. Kaolin from Lenggong and Tanjung Rambutan have silica content of 64.39% and 56.22%, iron content (Fe_2O_3) <1% and rutile content <1% meet the specifications of ceramic industry. Tanjung Rambutan kaolin also has potential to be commercialized as raw material for filler or coating material in paper or paint manufacturing. However, finer size particle should be used to improve its fired body properties. Shrinkage value for all clay in this project is significantly high which is > 11% but it is increasing with firing temperature from 700^{o}C to 1100 ^{o}C. There are several properties of Trong clay that meet the specifications of industry but its iron content is quite high for the clay to be used in industry. One of the way to improve the quality of the clay is to reduce the amount of iron content in the clay by using organic acid leaching method.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Clay is defined as a firm, fine-grained earth, plastic when wet, composed chiefly of hydrous aluminum silicate minerals: it is produced by the chemical decomposition of rocks or the deposit of fine rock particles in water and is used in the manufacture of bricks, pottery, and other ceramics.

Throughout ancient history, clay mineral is widely use in various range of industry. Around 9 000-10 000 BC, clay is first used as fuctional pottery vessel for water and food storage. People started making dishes and pots by using clay. It is also used for main material in production of brick. It is used for the above ceramic product because it exhibits permanent physical (shape) and changes chemically when fired in kiln.

There are several types of clay sell or used by domestic producer in the world market. These include ball clay, bentonite, common clay and shale, fire clay, fuller's earth and kaolin. Kaolin is one of the clay that has various uses for indusrial applications. In Malaysia, kaolin reserves located in Johor, Selangor, Perak, Kelantan, Sarawak and Pahang. Currently, kaolin mining are being carried out only in Pahang, Johor, and Perak. In 2016, production of kaolin decreased by 3.6 per cent from 294,693 tonnes to 284,023 tonnes produced in 2015 (Department of Geoscience Malaysia, 2016).

Most of the industrial kaolin in Malaysia was mined from secondary clay deposits. In Peninsular Malaysia, there are high quality kaolin deposits near Bidor and Tapah Perak, Cheras Selangor, Jemeluang Johore and recently, Sg. Rasau Pahang. However, it is unavoidable for high quality kaolin to deplete due to rapid exploitation and industrial demand. An effort need to be doneto find new kaolin deposits.

It is believed that there are some good clays that were not evaluated. It is important to assess these deposits in the economic aspects to determine their suitability for industrial applications and for subsequent exploitation and processing as well as their and value-added potential. Some specific physical and chemical properties of kaolin are dependent on the environment of deposition, geological origin, geographic source and the method of processing (Murray & Kogel, 2005).

Generally, kaolin deposit is classified as primary deposit or secondary deposit in term of geology and origin. Primary kaolin is a type of kaolin that formed at the site of the parent rock. Even though they are secondary in origin after other minerals, they are called primary kaolin. The example of primary kaolin deposit are Lampas and Keneras.

Secondary kaolin is a type of kaolin that formed after mineral fragments and rock transported as clays from the original site of origin. In other words, it is formed by transportation and redeposition of rock or mineral fragments. The examples of secondary kaolin deposit are Tapah and Bidor, Perak.

1.2 Problem Statements

The problem statement relates to the fact that the potential commercial of kaolin clay in various industry. Some specific physical and chemical properties of kaolin are depend on the environment of deposition and geological origin (Murray & Kogel, 2005). A primary kaolin deposit may have different properties compared to secondary kaolin deposit. Therefore, it is important to evaluate kaolin clay deposit from different origin and genesis based on their mineralogy, chemistry, physical and fired body property to determine their suitability for industrial applications and for subsequent exploitation and processing as well as their and value-added potential.

1.3 Research Objectives

The objectives of this research is:

1) To analyse the mineralogy, chemistry and industrial technical properties of kaolin clay from different origin and genesis

2) To determine their suitability for industrial applications

3) To evaluate the potential of kaolin clay deposit from different origin and genesis as an industrial raw materials by comparing the properties of the kaolin clay with the industrial specifications.

1.4 Research Scope

The research is done by collecting samples from three different kaolin deposits. It is believed that there are some good clays, which suspected to be kaolin clays that were not evaluated at Perak. The deposits located at Lenggong, Tanjung Rambutan and Trong, Perak. These deposits have different origin and genesis making them suitable for the purpose of this study. The thesis will investigate the properties of those clays and their potential as raw materials in various industrial applications.

1.5 Hypothesis

At the end of the project, the objectives of the project need to be achieved. The mineralogy, chemistry, physical and fired body properties of kaolin clay from different origin and genesis is analyzed. By using the result of all of the test, their suitability for industrial applications is determined and the potential of kaolin clay deposit from different origin and genesis as an industrial raw materials can be evaluated. The properties of all deposit can be compared with the industrial specifications.

CHAPTER 2

LITERATURE REVIEW

2.1 Kaolin

The name kaolin is based on the word Gao-Ling, a Chinese word, literally means 'high ridge'. Gaoling is a name of a hill near Jao Chau Fu, China. It is the place of the first kaolin was mined (Sepuldeva et al., 1983). It is also known as china clay. In the 7th and 8th centuries, the Chinese were the first to use kaolin to make porcelain. Usually, kaolin is refer as a clay that contain 10-95% of kaolinite mineral. Thera are also a small amount of other mineral such as quartz, mica, felsdpar, illite, montmorillonite, hematite, bauxite, zircon rutile, graphite, atapulgite and hallosite.

Kaolinite, the main mineral of kaolin that naturally formed by weathering process of rocks. It is white in color, small and thin in shaped.In mineralogy, The chemical formula for kaolinite is $Al_2Si_2O_5(OH)_4$. In ceramics applications, formula of kaolinite is typically written in terms of oxides as $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. During thermal treatment of kaolinite, it will undergo several transformation of phase

The first stage of transformation is drying. At temperature below 100 °C, exposed liquid water in the kaolin is removed slowly. Any remain water is removed from kaolinite between temperature 100 °C and 550 °C. The end condition for this change is referred to as "bone dry". The removal of water is reversible during this temperature range. This means that the kaolin will reabsorbed and break up into its fine particulate form if it is exposed to liquid water.

The second stage of transformation of kaolin is involving the formation of metakaolin. At 550–600 °C, disordered metakaolinis produced by endothermic dehydration of kaolinite, but continuous hydroxyl loss is observed up to 900 °C (1650 °F). Historically, there were many disagreements concerning the nature of the metakaolin phase. Therefore, a research was done and led to a conclusion that metakaolin is not a simple mixture of alumina (Al_2O_3) and amorphous silica (SiO_2). It is a complex amorphous crystal system that retains some longer-range order (but not strictly crystalline) due to stacking of its hexagonal layers. (Murray, 1951, p. 290)

$$Al_2Si_2O_5(OH)_4 \rightarrow Al_2Si_2O_7 + 2\ H_2O \qquad \text{(Eq. 2.1)}$$

The third transformation of kaolin is at a higher temperature compare to the formation of metakaolin. Metakaolin converts to an aluminum-silicon spinel at temperature 925–950 °C. Aluminum-silicon spinel also known as a gamma-alumina type structure. The chemical equation of the transformation is:

$$2\ Al_2Si_2O_7 \rightarrow Si_3Al_4O_{12} + SiO_2 \qquad \text{(Eq.2.2)}$$

At higher temperature, platelet mulliteis produced as the fourth transformation of kaolin. Further heating to 1050 °C, the spinel phase nucleates transforms to crystalline cristobalite and platelet mullite because of calcination. The chemical equation is:

$$3\ Si_3Al_4O_{12} \rightarrow 2\ (3\ Al_2O_3 \cdot 2\ SiO_2) + 5\ SiO_2 \qquad \text{(Eq. 2.3)}$$

The last stage of transformation of kaolin is involving the formation of needle mullite. At 1400 °C, the resistance of heat and strength of the structure is increase when mullite is formed (needle form). This is not a chemical transformation but a structural transformation. (Murray, 1951, p. 291)

2.2 Geology and Origin of Kaolin Deposit

Generally, kaolin deposit is classified as primary deposit or secondary deposit in term of geology and origin. Primary kaolin deposit is formed by hydrothermal alteration or residual weathering whereas secondary kaolin deposit are sedimentary in origin.

2.2.1 Primary Kaolin

Primary kaolin is a type of kaolin that formed at the site of the parent rock. Even though they are secondary in origin after other minerals, they are called primary kaolin. The example of primary kaolin deposit are Lampas and Keneras. They are classified as in-situ (primary type) of kaolin deposit.For in-situ weathering, the matrices generally contain well-crystallized kaolinite with low Fe substitution. This is because it inherited its parent-rock structure. Meanwhile, for clayey matrices, the matrices contain poorly-crystallized kaolinite with higher Fe substitution because it inherits blurred parent-rock structure. (Herbillon, 1980)

2.2.2 Secondary Kaolin

Secondary kaolin is a type of kaolin that formed after mineral fragments and rock transported as clays from the original site of origin. In other words, it is formed by transportation and redeposition of rock or mineral fragments. The examples of secondary kaolin deposit are Tapah and Bidor, Perak.

Usually,minerals such as micas and quartz are mixed secondary clays. Micas and quartz are more resistant to weathering.Therefore, they are not easy to be transported or redeposited from their original site. In the case of the upper beds, stream and wave action will separate the clay from the unweathered grains. It will carry the kaolin away by breaking the latter down to finer grain sizes. The kaolin is redeposited as distinct beds.

It may also be an economic significance for the kaolin that remain mixed with quartz sand grains and other minerals. For example, kaolinized sands. It is the lower beds of kaolin formation. These beds would contain an average of 50% kaolin which can be separated, purified and used in a variety of industrial applications.

2.3 Applications of Kaolin in Industry

The largest uses of kaolin is the paper industry, which used 75% of its production, which is approximately 1,200,000 tons in 1958 (de Polo, 1960, p. 207). In 2012, 45% of kaolin production is used for paper industry resulting the industry remains as the dominant consumer for kaolin clay.

Table 2.1: The percentage of kaolin uses in industry. (Roskill Information Services, Ltd. The Economics of Kaolin 10th Edition).

No.	Industry	Percentage of Uses
1.	Paper filling and coating	45%
2.	Refractories	16%
3.	Ceramic	15%
4.	Fibreglass	6%
5.	Cement	6%
6.	Plastics and Rubber	5%
7.	Paint	3%
8.	Catalyst	2%
9.	Others	2%

Kaolin act as a filler in the interstices of the sheet. It add receptivity of ink and opacity to the paper produced. The surface of the paper is also coated by using kaolin. It makes colors printed becomes bright and photographic illustrations becomes sharp. The paper produced by using kaolin as filler will print better, smoother and whiter. The kaolin properties such as low viscosity, whiteness, non-abrasiveness, flat hexagonal plates, and controlled particle sizes give important value to the manufacturing of paper. The kaolin particle size also influence the physical properties of kaolin such as brightness, viscosity, and gloss properties.(Lyons, 1958, p. 81).

Table 2.2: Industrial specification of kaolin as filler in paper making.

No.	Properties	Industrial Specification
1.	Moisture content	0-1%
2.	pH	4.0-5.0
3.	SG	2.68
4.	Colour	White
5.	MoR	2.0-2.5
6.	Particle Size Distribution <20mm <10mm <2mm	 98% 90% 48%
7.	SiO_2	46%
8.	Al_2O_3	37-38%
9.	Fe2O3	0.5-1.0%
10.	K2O	1%
11.	Na2O	0.2%
12.	MgO	0.18%
13.	CaO	0.1%
14.	TiO2	1%
15.	LOI	13.10%

The second consumer for kaolin is the manufacture of refractory products which consume about 16% of world kaolin production. The natural kaolin is heating to high temperatures, approximately 1050 °Cin a kiln producing aluminosilicate material, or known ascalcined kaolin. Calcined kaolin consists of mullite, cristobalite, and/or a silica alumina spinel (Brindley and Nakahira, 1959, p. 312).

The heating process is known as calcination process. This calcination process ensures consistent physical and chemical properties. It has low water absorption, high melting point, low body thermal expansion and hardness.However, the product surface is totally changed physically and chemically making the product of calcined become whiter and more abrasive than the original kaolin. Example of utilization of calcined kaolin is in paint, rubber, and plastics.

Another large consumer of kaolin is the manufacturing of ceramic products which consumes about 15 % of the world kaolin production. The example of ceramic product is tiles, roof and whiteware products. Kaolin helps to control the properties of molding in whitewares. It also improved the stability of dimensional, strength of dry and fired body and gives the surface of the ware a smooth finishing.

Other than that, kaolin is also used as raw material to make porcelain electrical insulators. It has chemical inertness and dielectric properties make kaolin an important constituent. The high fusion point, excellent dimensional stability, low water content and high green strength, make it suitable to be used in refractory applications.

Table 2.3: Industrial specification of kaolin in ceramic industry.

No.	Properties	Industrial Specification
1.	Moisture content	0-1%
2.	pH	4.0-5.0
3.	SG	2.68
4.	Colour	White
5.	MoR	2.0-2.5
6.	Particle Size Distribution <20mm <10mm <2mm	 98% 90% 48%
7.	SiO_2	56-70%
8.	Al_2O_3	36.1-37%
9.	Fe2O3	0.6-1%
10.	K2O	1%
11.	Na2O	0.2%
12.	MgO	0.18%
13.	CaO	0.1%
14.	TiO2	1%
15.	LOI	13.10%

The manufacturing fibreglass also used kaolin as one of the ingredients. About 6% of kaolin production is used in 2012 for manufacturing of fibreglass. It is used as a filler that enables to make the fibres integrated into the material stronger. Products such as cars, boats, pipes, required strengthened plastics.

Kaolin also helps to improve the fibres integration in products. Therefore, fibreglass is often used for fibreglass building and construction products. The surface composition of the fibre, chemical nature and properties, and the textile structure of the reinforcing system is determined by the kaolin concentration in the binder.

The next application for kaolin is in the cement products. A research is conducted to replace cement with calcined kaolin. The research is done by replacing conventional cement concrete with calcined kaolin. The reactivity of the material determined The range of replacement for calcined kaolin. Between 5 and 30% of the cement may substitute with calcined kaolin by mass. It shows that concrete made with calcined kaolin generates less bleed water than conventional cement concrete (Balogh, 1995).

The calcined kaolinite acts as an accelerator when replacing cement at 30% by mass, (Ambroise, 1994). One research project showed that for optimum strength, the calcined kaolin replacement range is 5-10% by mass (Walters and Jones, 1991). In 2012, manufacturing of cement consumed about 6% of the world kaolin production.

Kaolin is also used in many rubber and plastics goods as a fillerwhich is approximately 5% of world production of kaolin . It will improved the resistance, abrasion, strength, and rigidity to synthetic and natural rubber products. Usually, after kaolin filler is added most products of rubber extrude more easily. Kaolin is low in cost, and its whiteness is the major cause that kaolin is used in rubber manufacturing. It has excellent functional properties although kaolin costs less than most other rubber pigments.

In manufacturing of plastic products, kaolin will make attractive finish, surfaces become smoother, better resistance to the chemical attack and high dimensional stability. In mineralogy, kaolin has flat hexagonal kaolin plates. It can helps to simplify the molding of complex shapes by giving the mix flowability to the products and hiding the reinforcing fibres of the products.

For other applications such as paint, catalyst, ink, fertilizers, detergents, adsorbents, and others, the total percentage of kaolin uses is 7%. The major reason kaolin is used in the production of paint is it is insoluble and chemically inert in the paint system. It also low cost compare to other raw material and make the flow properties of paint as desired by the manufacturer.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The project is started by using Auger sampling technique for initial field investigation. After the raw samples are obtained, sample preparation is done by grinding and sieving process. The sieving process is done to remove sand and to obtain desired sample size for each test. X-ray diffraction (XRD) and chemical analysis using X-ray fluorescence (XRF) is used to study the petrography and mineralogy of kaolin samples. The composition and the degree of crystallinity and structure of the kaolin clay minerals is identified and confirmed by infrared (FTIR) spectrophotometer.

The thermal reactions during the heating process is determined by thermogravimetric analysis (TGA) and differential thermal analysis (DTA). It also used for purity determination of kaolin clay. Samples of kaolin clay will also going to be analyzed by using pre-determined size range sedimentation device in order to investigate particle size analysis and classification of kaolin. Most analyses are carried out for particle size of less than 75 µm. Scanning electron microscope (SEM) and energy dispersive X-ray (EDX) is also used to identify and confirm the particle size, crystal morphology and composition of the kaolin clay. The tests such as moisture content, iron content, loss on ignition (LOI), pH, moisture, plasticity and specific gravity is also done to investigate the industrial technical properties of kaolin.

For ceramic requirement, other specific tests including firing test (color before and after) and shrinkage test, as well as modulus of rupture (MoR) and water absorption is going to be conducted at various firing temperature levels in a laboratory electrical muffle furnace. MoR tests are conducted for samples with top-cut size of < 45μm whereas shrinkage tests are conducted for particle size < 75 μm.

Atterberg apparatus is used to determine the plastic limit (PL), liquid limit (LL) and plastic index (PI) of kaolin clay. British Geological Survey (BGS) procedure for kaolin (Bloodworth et al., 1993) are used as a standard. For moisture content, iron content, moisture, plasticity and specific gravity, these tests were conducted in accordance to BS 1377 Part 2 1990 and other relevant procedures. For loss on ignition (LOI) and pH test, BS 1377 Part 3 1990 are used.

3.2 Flowchart of Research Work

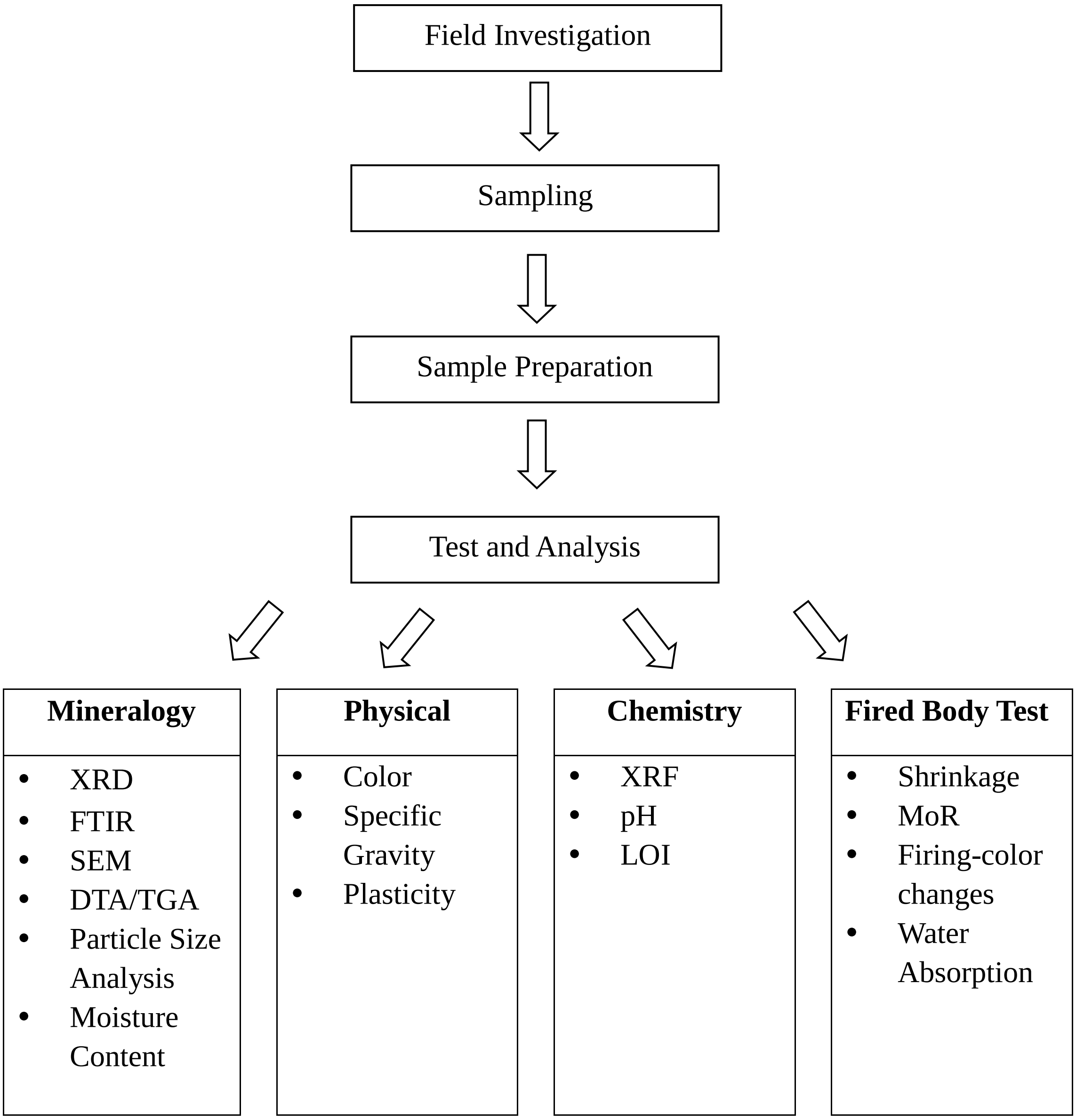

Figure 3.1: Flowchart of the methodology.

3.3 Location and Geology of Sampling Area

3.3.1 Lenggong

The first deposit for this project is located at Lenggong, Perak. This newly-discovered primarily kaolin occurrence located 5 km from Kampung Tenaga Baharu at Ayer Jada.

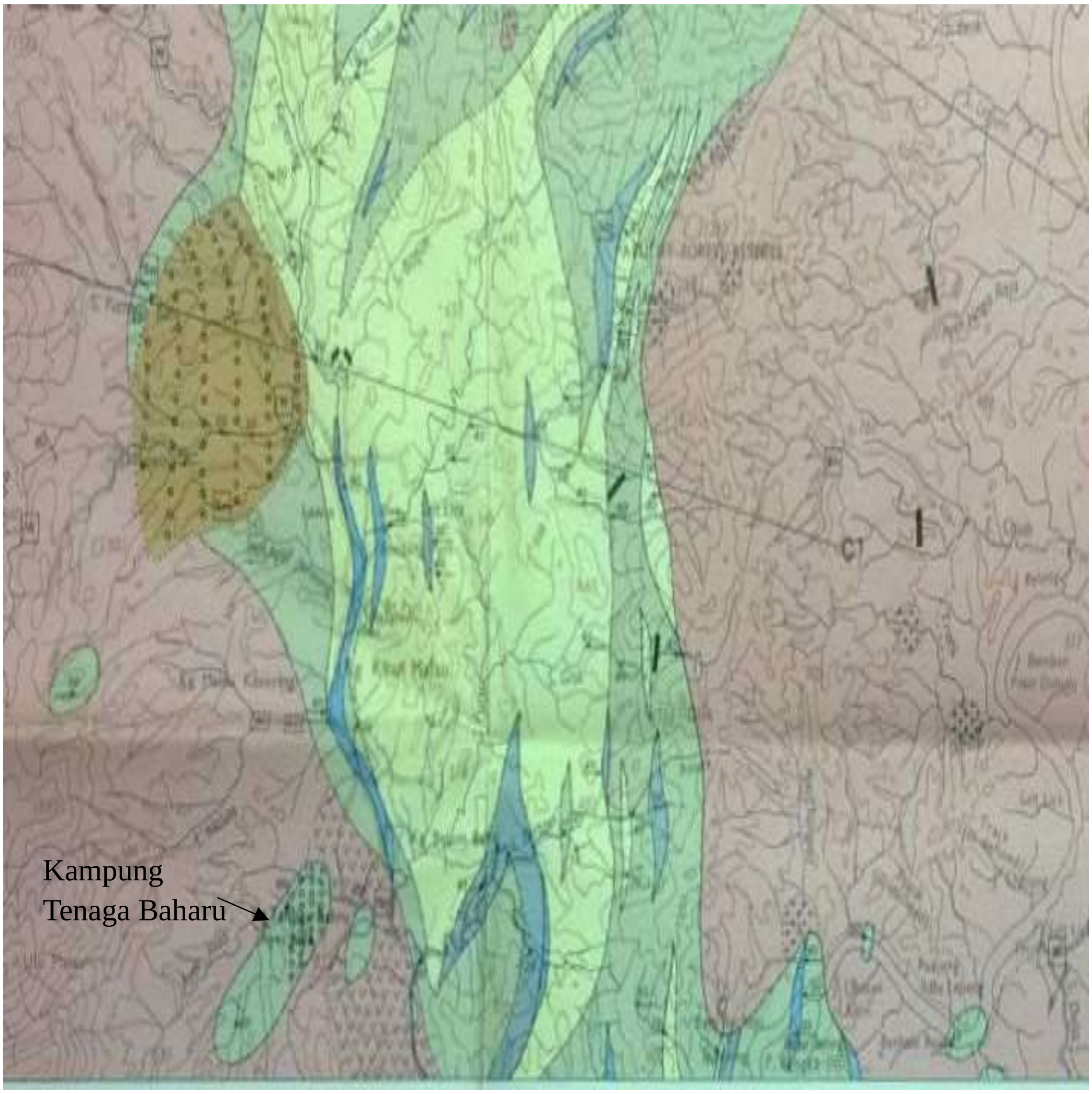

Figure 3.2: Map showing location of Kampung Tenaga Baharu, 5 km from the first deposit of this project. (Directorate of National Mapping, Malaysia, 2017).

It is a primary clay deposit with suspected tuff as parent rock. The deposit exposed soil profile shows that the kaolin clay is covered by overburden with an average thickness of 1m. The sample is taken at the surface of the deposit.

a) b)

Figure 3.3:a) The deposit exposed soil profile shows that the kaolin clay is covered by overburden with an average thickness of 1m. b) Collected sample from Lenggong deposit.

3.3.2 Tanjung Rambutan

The second deposit for this evaluation located at near Bukit Kinding at Tanjung Rambutan. It is located 6.6km from Tanjung Rambutan town.

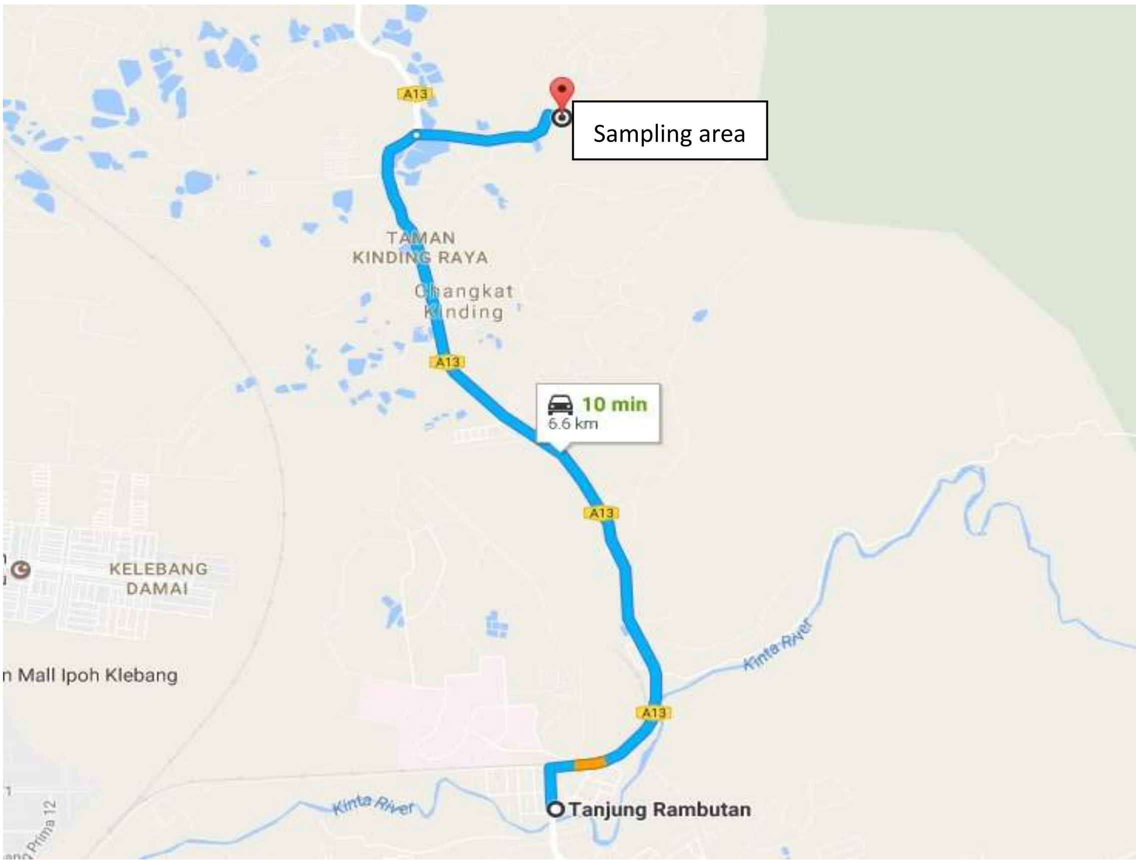

Figure 3.4: Map of sampling near Bukit Kinding and the town of Tanjung Rambutan, Perak. (Googlemaps, 2017).

It is a primary deposit of kaolin clay. It is exposed on a cut slope at 938. The slope has a length of 170m, height of 25m, and facing the direction of 70 degrees. The terrace exposed soil profile shows that the kaolin clay is covered by overburden made up lateritic soil, with an average thickness of 7m. The granitic texture of the parent rock is preserved, and there are visible quartz veins with thickness ranging from 5to 15cm which dips 70 degrees to the direction of 50. 2. A sample of crude clay is collected from this location, which labelled as TR 1.

Figure 3.5: Satellite image of sampling area on a slope at 938.(Googlemaps, 2017).


Figure 3.6: The terrace exposed soil profile shows that the kaolin clay is covered by overburden made up lateritic soil, with an average thickness of 7m.

3.3.3 Trong

The third deposit for this study located at Kampung Salak Baru, Trong. It is a secondary clay deposit.

Figure 3.7: Map showing location of Trong clay deposit at Kampung Salak Baru, Trong. (Googlemaps, 2017). Sampling area is labelled as TA1.

Currently, the deposit is a mined area. It is composed primarily ofkaolinite with minor to major amount other minerals, quartz and organic material. It is choosed to be include in this study to investigate its potential as raw material in various industry.

Figure 3.8: Stockpile of the clay at Trong, Perak.

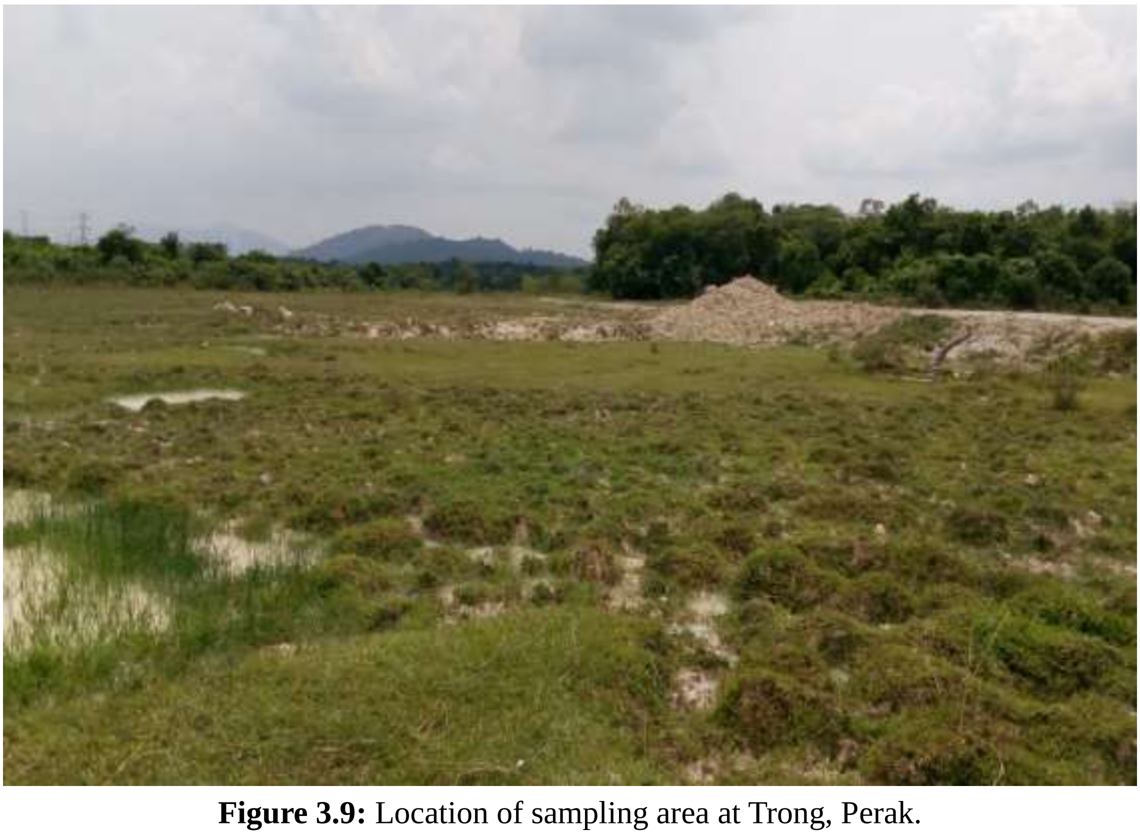

Figure 3.9: Location of sampling area at Trong, Perak.

Figure 3.10: Trong sample obtained by Auger sampling technique.

3.4 Sampling Method

3.4.1 Auger Sampling Technique

Auger sampling technique is usually used for sand,silt, mud and soft clay. For stiff clay and gravel, it is impossible to apply this method of sampling unless it is combined with percussion. This technique is more suitable to obtain soil sample of fine grain particle.

The hand auger is one of the simplest manual drilling methods. Presently hand auger drilling is one of the most common hand drilling technique. It consists of extendable steel rods, rotated by a handle. A number of different steel augers (drill bits) can be attached at the bottom end of the drill rods. The augers are rotated into the ground until they are filled, and then lifted out of the borehole to be emptied. A different auger can be used for each formation (soil) type. As the depth increases additional drilling rods are added until the desired depth is reached.

a) b)

Figure 3.11: a) Auger sampling technique is carried out during field investigation using steel rod with handles, b) The steel rod is rotated into the ground.

a) b)

Figure 3.12: a) Sample obtained for one drill hole. b) Sample obtained for one drilling (30cm).