QUANTIFICATION OF CLAY MINERAL IN SHALE COMPARED WITH WELL LOG INTERPRETATION FROM SAN SAI OIL FIELD, FANG BASIN, CHIANG MAI PROVINCE

NATTAPINYA NAKAWONG

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การหาปริมาณแร่ดินในหินดินดานเปรียบเทียบกับการแปลข้อมูลหยั่งธรณี หลุมเจาะจากแหล่งน้ำมันสันทราย แอ่งฝาง จังหวัดเชียงใหม่

นางสาวณัฐภิญญา นาคะวงค์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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อาจารย์ที่ปรึกษา: ผู้ช่วยศาสตราจารย์ ดร. บัณฑิตา ธีรกุลสถิตย์, 102 หน้า.

คำสำคัญ: เศษหินที่ได้จากการขุดเจาะ/การบวมของหินดินดาน/แร่มอนต์มอริลโลไนต์/แร่อิลไลต์

วัตถุประสงค์ในการวิจัยครั้งนี้คือ (1) เพื่อศึกษาแร่และธาตุประกอบของหินดินดาน (2) เพื่อเทียบสัมพันธ์ธรณีเคมีของหินดินดานและข้อมูลการหยั่งธรณีของหลุมเจาะ และ (3) เพื่อคาดการณ์แนวโน้มบริเวณที่จะเกิดปัญหาจากการบวมของหินดินดานของหลุมเจาะ FA-SS-35-04 ในแหล่งน้ำมันสันทราย ของแอ่งฝาง ตัวอย่างเศษชิ้นหินทั้งหมดจากหลุม FA-SS-35-04 ถูกรวบรวมมาศึกษา ซึ่งประกอบด้วย 8 ตัวอย่างจากหมวดหินแม่ฝาง และ 39 ตัวอย่างจากหมวดหินแม่สอด (หน่วยหินเอ หน่วยหินบี และหน่วยหินซี) การวิเคราะห์แร่และธาตุประกอบของหินดินดานได้ทำการวิเคราะห์โดยเครื่องมือการเลี้ยวเบนของรังสีเอ็กซ์ (XRD) และการเรืองแสงของรังสีเอ็กซ์ (XRF) ตามลำดับ กล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด (SEM) ถูกใช้เพื่อการศึกษาสัณฐานวิทยาระดับจุลภาคของหินดินดาน การเทียบสัมพันธ์ระหว่างข้อมูลการหยั่งธรณีของหลุมเจาะ และปริมาณแร่ดินในหินดินดานที่ได้จากเศษชิ้นหิน จากผลการศึกษาของหมวดหินแม่ฝาง มีแร่มอนต์มอริลโลไนต์ ปริมาณเฉลี่ยร้อยละ 1.68 ซึ่งมีแนวโน้มค่อนข้างคงที่หรือเพิ่มขึ้นเล็กน้อยตามความลึก ส่วนแร่อิลไลต์ แคโอลิไนต์ และคลอไรต์ มีปริมาณเฉลี่ยร้อยละ 0.42 0.11 และ 0.11 ตามลำดับ ในหมวดหินแม่สอด มีแร่มอนต์มอริลโลไนต์ ปริมาณเฉลี่ยอยู่ที่ร้อยละ 3.91 ซึ่งมีแนวโน้มค่อนข้างคงที่และเพิ่มขึ้นเล็กน้อยตามความลึก แร่อิลไลต์ แคโอลิไนต์ และคลอไรต์ มีปริมาณเฉลี่ยร้อยละ 10.15 17.4 และ 0.99 ตามลำดับ จากผลการศึกษาแร่มอนมอริลโลไนต์เป็นแร่หลักที่ก่อให้เกิดการบวมของชั้นหินดินดาน ซึ่งแร่นี้มีแนวโน้มเพิ่มขึ้นตามความลึกของหิน โดยเฉพาะหน่วยหินบีและหน่วยหินซีของหมวดหินแม่สอด ซึ่งสัมพันธ์กับปริมาณเฉลี่ยของ MgO, Na_2O, CaO และ Al_2O_3 ที่ร้อยละ 2.35 4.82 3.99 และ 14.02 ตามลำดับ ผลการศึกษาการหยั่งธรณีแสดงการเปลี่ยนแปลงของค่าความพรุนและความหนาแน่นในชั้นหิน และการหยั่งธรณีแบบแกรมม่ายัง แสดงถึงปริมาณของหินดินดานมีแนวโน้มเพิ่มขึ้นตามความลึกในหน่วยหินเอชั้นบน ซึ่งแนวโน้มลดลงตามความลึกในหน่วยหินเอชั้นล่าง และเพิ่มขึ้นในหน่วยหินบีและหน่วยหินซีในหมวดหินแม่สอด ดังนั้นจากผลการเทียบสัมพันธ์ระหว่างผลธรณีเคมีและการหยั่งธรณีหลุมเจาะ ทำให้คาดการณ์ได้ว่าหินดินดานในหมวดหินแม่สอดเป็นชั้นหินหลักที่มีแนวโน้มที่จะเกิดปัญหาจากการบวมของหินดินดาน ในแหล่งน้ำมันสันทราย โดยเฉพาะหน่วยหินบีและหน่วยหินซี ซึ่งมีค่าเฉลี่ยแร่มอนต์มอริลโลไนต์สูงที่สุดคือร้อยละ 5.30 และ 5.54 ตามลำดับ

สาขาวิชา เทคโนโลยีธรณี
ปีการศึกษา 2565

ลายมือชื่อนักศึกษา..........
ลายมือชื่ออาจารย์ที่ปรึกษา..........

NATTAPINYA NAKAWONG: QUANTIFICATION OF CLAY MINERAL IN SHALE COMPARED WITH WELL LOG INTERPRETATION FROM SAN SAI OIL FIELD, FANG BASIN, CHIANG MAI PROVINCE. THESIS
ADVISOR: ASST. PROF. BANTITA TERAKULSATIT, Ph.D., 102 PP.

Keywords: DRILL CUTTINGS / SHALE SWELLING / MONTMORILLONITE / ILLITE

The purpose of this research is (1) to study the mineral and elemental composition of shale, (2) to correlate the geochemical of shale and well logging data, and (3) to predict the trend of the area impacted by shale swelling within San Sai Oil Filed, Fang Basin. All borehole cuttings from FA-SS-35-04 well were collected, including 8 samples of Mae Fang Formation and 39 samples of Mae Sod Formation (Unit A, Unit B, and Unit C). Mineral and elemental compositions of clay were determined with the use of X-ray diffractometers (XRDs) and X-ray fluorescence (XRFs). A scanning electron microscope (SEM) was used to examine the morphology of the microstructure of shale. A correlation between the well logging data and the quantification of clay minerals in shale obtained from the borehole cuttings. Based on Mae Fang Formation results, montmorillonite content averaged 1.68%, which is fairly stable and slightly increases with depth. Illite, kaolinite, and chlorite contents were average at 0.42%, 0.11%, and 0.11%, respectively. In the Mae Sod Formation, the montmorillonite content averaged 3.91%, which is fairly stable and will tend to increase slightly as depth increases. The contents of illite, kaolinite, and chlorite are 10.15%, 17.4%, and 0.99%, respectively. The montmorillonite has a strong effect on swelling and is slightly increased within the shale layer, especially with Unit B and Unit C of Mae Sod Formation which are related to the average content of MgO, Na_2O, CaO, and Al_2O_3 at 2.35%, 4.82%, 3.99%. and 14.02%, respectively. The Gamma Ray logs showed that the shale volume increased with depth in Upper Unit A, decreased with depth in Lower Unit A, and increased with depth in Unit B and C of Mae Sod Formation. Ant The Density and Neutron log showed that the range of density was 1.93-2.45 g/cc, which is the density of shale and sandstone, and the range of porosity (3.8-8) in shale formation and showed high porosity in sandy shale. Therefore, based on the correlation of geochemical

results and well logs, it could be predicted that shale in the Mae Sod Formation was the major contributor to shale swell in the San Sai Oil Filed, particularly from Unit B and Unit C, where montmorillonite concentrations were highest at 5.30% and 5.5%, respectively.

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Advisor's Signature Pantitha Tesukulamat

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Nattapinya Nakawong

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SYMBOLS AND ABBREVIATIONS

g/cc	=	Grams per cubic centimeter
ft.	=	Feet
GR	=	Gamma Ray
PU	=	Per Unit
Fm	=	Formation
Mon	=	Montmorillonite
Il	=	Illite
Q	=	Quartz
K	=	Kaolinite
Ch	=	Chlorite
Ca	=	Calcite
Feld	=	Feldspar
Avg	=	Average
XRD	=	X-Ray Diffraction
XRF	=	X-Ray Fluorescence
SEM	=	Scanning Electron Microscope

CHAPTER I
INTRODUCTION

1.1 Rationale and Background

Fang Oil field is in Chiang Mai province the north of Thailand Fang oil field is the first seep on the ground surface and the oldest oil field. The basin is an intermountain basin near the Myanmar border approximately 18 kilometers wide and 60 kilometers long. It has a half-graben geometry. The one oil field is important for resource energy that has been developed and produced until the present.

One of the problems during oil and gas production is drilling through shale Formation. The Effective shale effect to erroneous values of water saturation and porosity as calculated from logs. Effective shale referred to as the shale is usually predominantly the multilayer clays such as smectites (montmorillonite, bentonite, etc.) and illite. They have significant CEC (Cation exchange capacities). The non-effective shales are the kaolinites and chlorites with essentially have CEC. Petroleum exploration and production requires drilling, which involves drilling through geologically diverse rock Formations. The properties of mud water must be adjusted to appropriate the rock layer. One problem is shale swelling, the effect of absorbing water from clay minerals such as montmorillonite cause stuck pipe and interpret logging. Thus, the study object is the correlation between physical properties, chemical properties, and data to predict problem zone from shale swelling to avoid and protect from shale swelling to find ways to resolve the swelling of the shale and provide information for further drilling planning.

1.2 Research Objectives

The main objectives of this study are as follows.

1.2.1) Correlate the geochemical clay minerals of shale and logging.

1.2.2) Study the clay mineral and element of the shale in the San Sai Oil Filed, Fang Basin.

1.2.3) Identify the problem zone from shale swelling.

1.3 Scope and Limitations of the Study

The Laboratory test is operated at the laboratory of Suranaree University of Technology following:

The purpose of this research is to study the physical and chemical properties of shale to predict the shale swelling zone. The properties are tested at Suranaree University of Technology, Thailand. The scope and limitations of the research are as follows.

1.3.1) All samples are washed and dried cuttings from FA-SS-35-04 well, San Sai oilfield, Chiang Mai province.

1.3.2) Logging data from FA-SS-35-04 well of San Sai oilfield is Gamma-ray (GR), density, and neutron log.

1.3.3) Physical property was analyzed by using a compound light microscope and scanning electron microscope (SEM)

1.3.4) Chemical property was analyzed by Using an X-ray diffractometer (XRD), and X-ray fluorescence (XRF).

1.4 Thesis Contents

The thesis comprises five chapters. **Chapter I** describes the importance of this study and its problems including rationale and background, research objectives, scope, and limitations of the study. **Chapter II** shows the result of the literature review to understand the characteristics of lithology and factors to identify the problem zone comprising general geology of northern Thailand and the study area, shale swelling, clay mineral, principle of clay mineral analysis, and the principle of logging analysis. **Chapter III** describes the methodology and sample collection, and shows the equipment and data used in this study. **Chapter IV** presents the result from cuttings, chemical properties, and logging data, and discusses and identifies the problem zone. **Chapter V** summarizes the study results and recommendations for future research studies:

CHAPTER II
LITERATURE REVIEW

This chapter of the literature concerns about geological setting of the Fang Basin, Gamma-ray log, Neutron log, Density log, and clay mineral of FA-SS-35-04 well in Fang Basin, Chiang Mai province, Thailand. The result of the literature review is below as follows.

2.1 Geological Setting of Fang Basin

Fang oil field It is the first oil field in Thailand. Located in the Fang Basin, drilling and producing petroleum for more than 100 years, with exploration and production drilling in the Fang District, Chiang Mai Province. It has a half-graben geometry (Sethakul, 1985), and the boundary is the west by a curved east-dipping fault which, at the north end of the basin, turns into the Mae Chan Fault which trends ENE-WSW and has a strike-slip sense of motion. The Fang Basin is located on the western side of the Sukhothai fold belt, which comprises Paleozoic and Triassic strata and volcanic rocks that were accumulated on the eastern margin of the Shan-Thai Craton before the Indonesian orogeny. This fold belt is complex and trends north and Northeast-southwest. These rocks were uplifted and deformed by granitic intrusions during the collision of the Indochina and the Shan-Thai Cratons (Bunopas and Vella, 1983).

In the Fang Basin, Sethakul (1985) divided sediments and rocks into two units based on their formation including the Mae Fang and the Mae Sod Formations.

The Mae Fang Formation (Quaternary and recent) is primarily composed of coarse clastic sediments, including soil, sand, gravel, cobbles and pebbles, carbonized woods, and clay. Sizes of sand vary from coarse grains to very coarse grains, roundness from angular to sub-angular, poorly sorted, and interbedded with reddish clays. Clay-shale and arkose sandstone are interbedded down the dip towards the central basin. Mae Fang Formation overlies the Mae Sod Formation and shows energetic alluvial and fluvial deposits.

The Mae Sod Formation (Middle Tertiary) consists of brown to gray shale, yellowish mudstones generally interbedded with sand, sandstone, and paleodelta channels and fluvial sand

The San Sai Oil Filed is approximately 1.7 square kilometers. This study covered about 22 square kilometers in UTM coordinates in WGS84 system at 5515473 to 524177 N and 2196042 to 2201293 E (Kongurai, 2013).

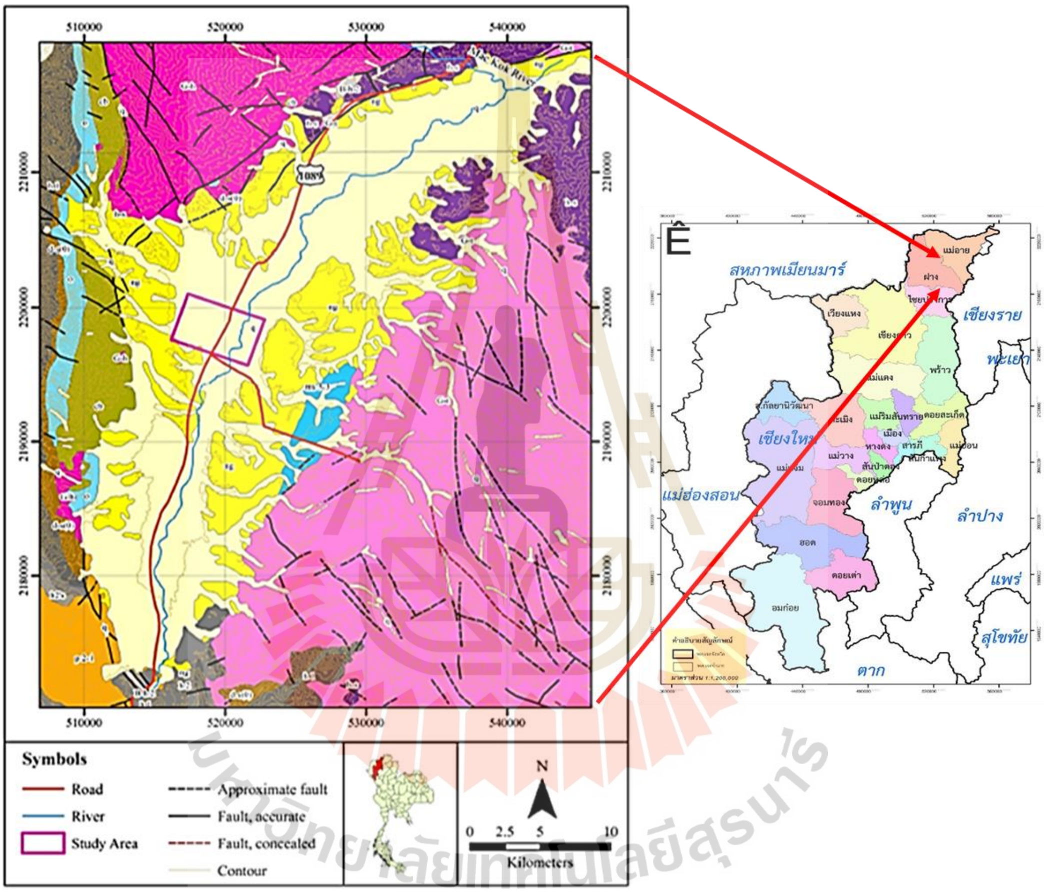


Figure 2.1 Geological map of Fang Basin (Khantaprab and Keawsang, 1987).

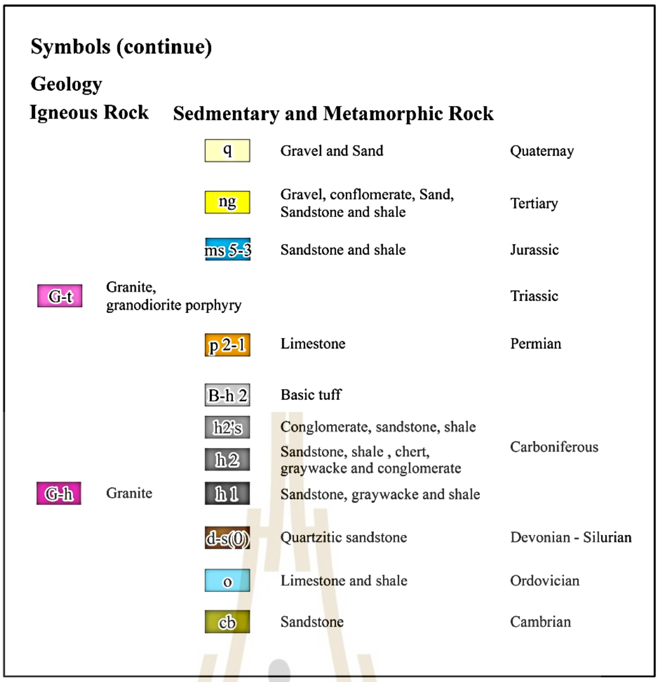


Figure 2.2 The Symbols for the geological map of Fang Basin (Khantaprab and Keawsang, 1987).

The Fang Basin in northern Thailand is half-graben and has a major bounding fault on its western margin. The area was historically known for its oil seeps and first petroleum production. A strike-slip fault divides the basin into three subbasins distinguished by older rocks on either side. Miocene-Pliocene lacustrine sediments of the Mae Sot Formation are the main targets for petroleum exploration, including organic-rich shales, lignite, and reservoir-quality sandstone. Those oils from the freshwater lacustrine shales containing high levels of algal material are waxy. Tertiary sediments reach a maximum thickness of 3000 m. Geothermal gradients are high (7.5°C/100m), possibly reaching 9.3°C/100m (Petersen, et al., 2006).

For drilling operations in offshore oil fields, rotary drilling rigs are commonly used. The most commonly used drilling fluid is water-based mud. In drilling mud, water dominates, and sedimentary consists primarily of shale. In contact with water, the shale components of drilling mud swell, leading to various issues, including pipe sticking. In order to prevent such problems, it is important to consider the properties of the drilling mud, as well as the composition of the shale. In this way, drilling operations are carried out smoothly and without complications that could delay or damage the drilling process.

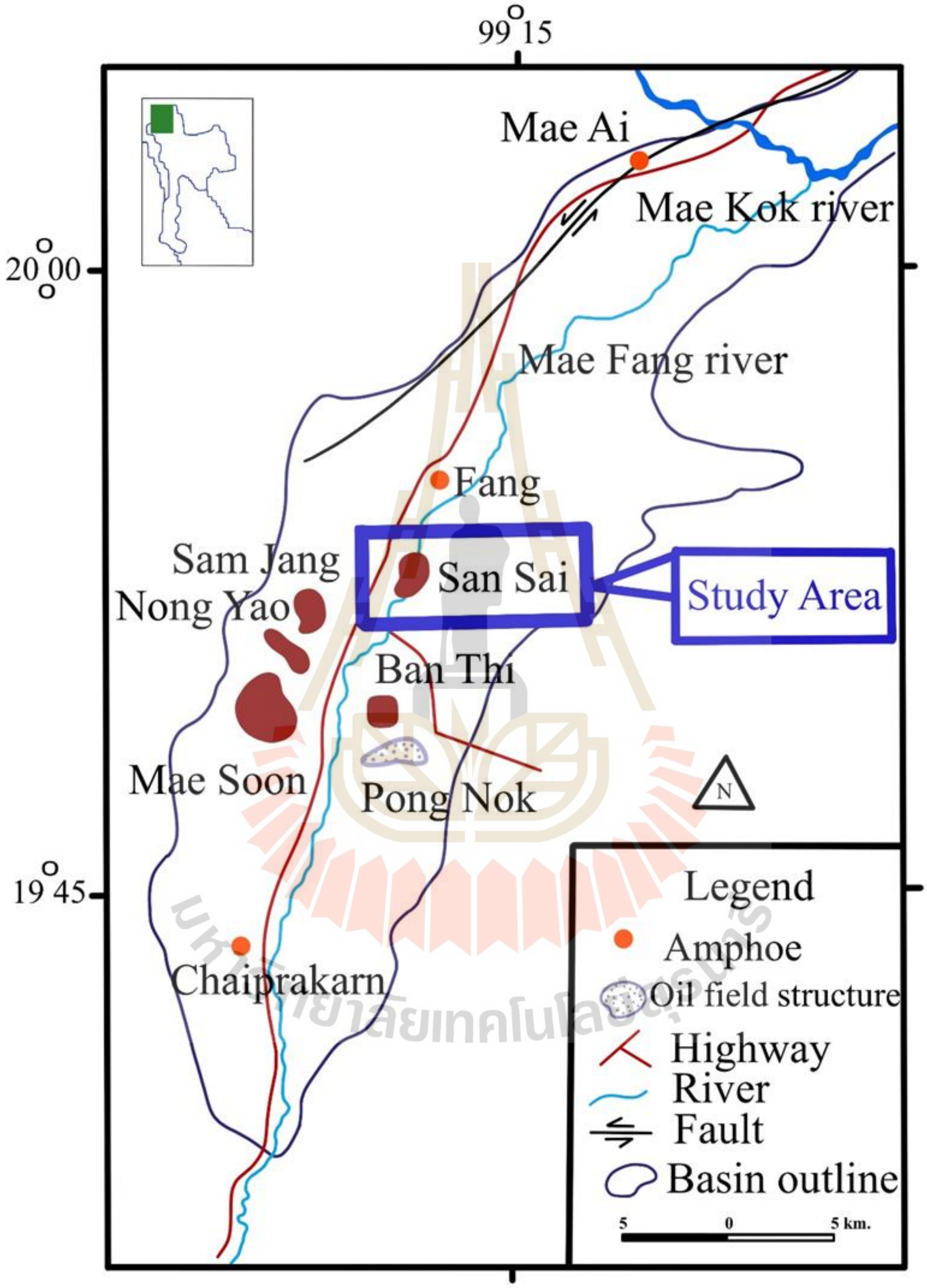


Figure 2.3 Oil Field of Fang Basin (Modified after Latt and Giao, (2012); Pitumwong (2011)).

2.2 Study Area

In 1921, villagers in Fang district discovered dark-colored oil seeping up through the soil. Some people believed it to be a sacred oil that possessed healing properties. Upon receiving this information, Chiang Mai's ruler ordered the excavation of an oil well. The Lord of Chiang Mai ordered a shallow well to be built and named the "Lord's Well". The memorial well is now called "Boh Tonkam". As shown in Figure 2.4.

Figure 2.4 Boh Tonkam well (Settakul, 2009).

Petroleum is mainly produced from nine oil fields: Ban Rai, Ban Thi, Mae Pa Phai, Mae Soon, Nong Yao, Pong Nok, Pong Sai Kha, Nong Sam Jaeng, and San Sai. The source areas are in the central part of the Fang Basin, which is divided by major fault lines (Defense Energy Department, 2016).

FA-SS-35-04 well is a petroleum well in the San Sai Oil Filed located in the Fang Basin at 19°52' 35" N and 99°12' 12" E. The well was drilled into the San Sai oil reservoir and is composed of Mae Fang and Mae Sod Formations. The stratigraphy of the FA-SS-35-04 well is shown in Figure 2.5.

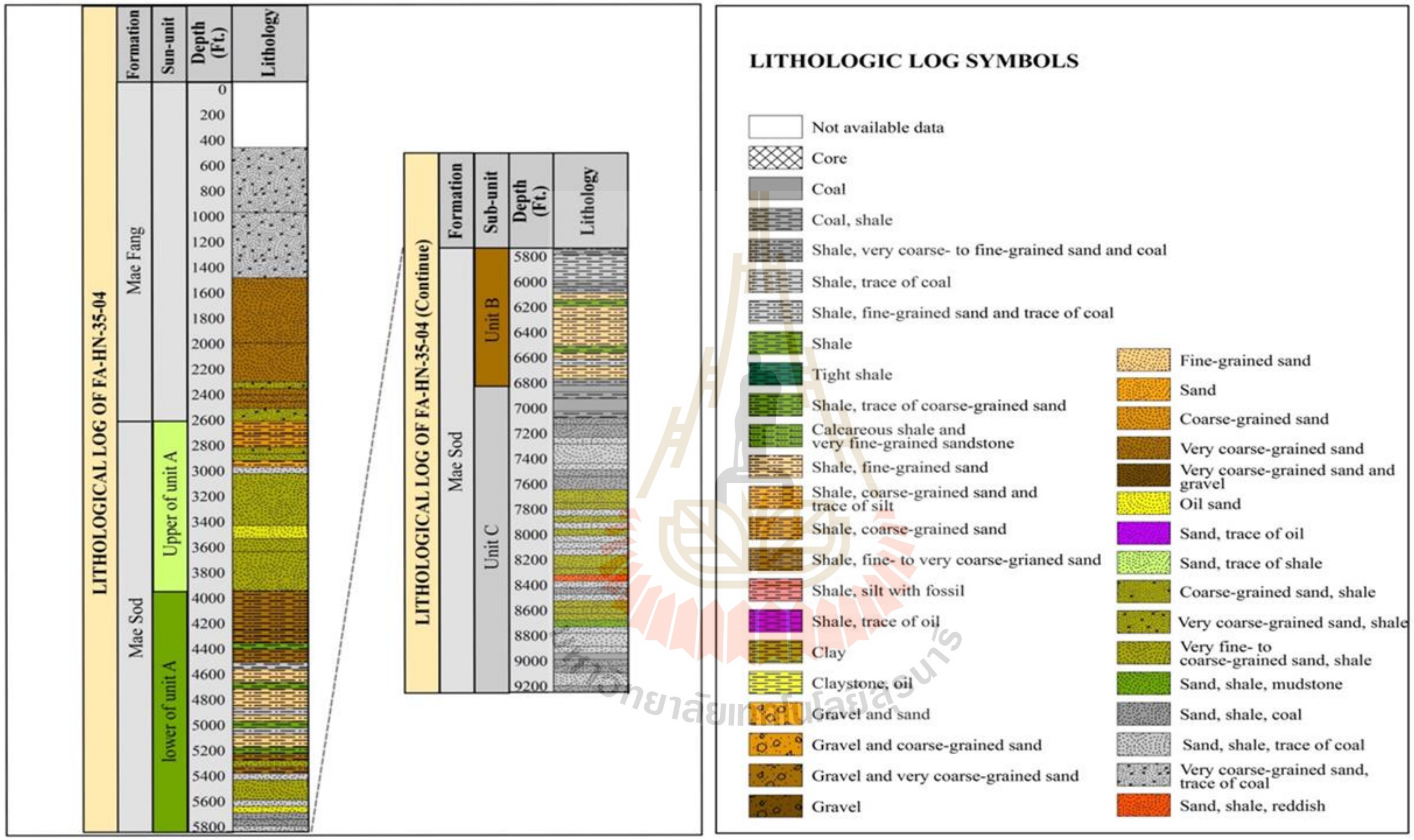


Figure 2.5 Lithology of FA-SS-35-04 well (Kongurai, 2013).

2.2.1 Mae Fang Formation

Mae Fang Formation is the uppermost section of the geological formation in the region. Approximately 500 feet thick, it consists primarily of sandy deposits with occasional thin layers of gravel, clay, and coal. There is a relatively thin layer of topsoil. A light to dark gray sand occurs in this formation, with coarse to very coarse grains, some granules, and moderate sorting. On the other hand, the gravel tends to be light gray to gray and poorly sorted, consisting of coarse to very coarse-grained sand.

It is common for the clay within the formation to be gray in color. The lithological succession in the region consists of immature sand and gravel, with an abundance of sand and poor to moderate sorting. Gravel and sand deposits are highly angular. These deposits have a tabular or wedge shape and may have formed in a high-energy environment associated with braided stream systems. In the braided stream facies, there are significant amounts of medium-grained sandstone, which were deposited on a steep slope.

The formation is underlain by sand interbedded with shale, which has an estimated thickness of 2,000 feet. In this sequence, the sand is between light gray and dark gray in color, with medium to coarse grain sizes and well-sorted characteristics. Shale layers within this sequence range in thickness from 7 to 25 feet and are generally dark gray in color.

Sand and clay deposits are deposited in a fining upward sequence under a meandering fluvial system. This thick clay unit probably formed because of a low-energy environment such as an ephemeral lake on the floodplain. According to the overall sedimentary facies, a meandering stream influenced the deposition primarily.

2.2.2 Mae Sod Formation

The Mae Sod Formation is divided into 3 sub-units (A, B, and C) respectively in descending order.

Sub-unit A, the geological unit can be further subdivided into parts. The upper part (Upper Unit A) is composed of interbedded shale and sandstone, with shale being the dominant lithology. This upper part has an approximate thickness of 1,400 feet. The shale is characterized by colors gray to dark gray and brown, while the sandstone is generally light gray to gray color. The sandstone is medium - to very coarse- grained and mostly well-sorted. Some of the sandstone beds within this part show indications of oil presence. The upper part is interpreted to represent the marginal lacustrine facies, suggesting deposition occurred at the fringes of a lake environment.

The lower part (Lower Unit A) of the unit primarily consists of thick shale layers with intermittent intercalations of fine-grained sandstone. This sequence has a total thickness of approximately 1,000 feet. The shale is characterized by dark gray, black, and dark brown colors, and it also contains some coal layers. This lower part is interpreted to represent a range of lacustrine facies, indicating deposition in a shallow to deep lake environment.

Sub-unit B is characterized by the presence of a mainly thick bed of dark gray shale, fine-grained sandstone, and coal. These lithological successions indicate deposition in a low-energy environment associated with a freshwater paleo-lake. The sediments that accumulated in this environment gave rise to sedimentary rocks exhibiting lacustrine facies.

Sub-unit C is characterized by a lower section comprising interbedded sandstone and coal beds, along with layers of black shale. The upper part of this sub-unit consists primarily of coal beds, with a thickness of around 200 feet, interspersed with some sandstone. The sandstone in this unit shows colors from red to gray and is fine- to very coarse-grained, occasionally containing layers of very clean sand. These sedimentary characteristics suggest deposition in marginal lacustrine facies.

The Mae Sod Formation is interpreted to be deposited in a meandering stream and lacustrine. The coal seam is regarded to be deposited under marginal lacustrine conditions.

2.3 Shale Swelling

Shale is a sedimentary rock composed of fine-grained clastic sedimentary rock made of compacted mud consisting of clay and tiny particles of quartz, calcite, mica, pyrite, other minerals, and organic matter. Shale forms in very deep ocean water, lagoons, lakes, and swamps where the water is still enough to allow the extremely fine clay and silt particles to settle to the floor. The defining characteristic of shale is its ability to break into layers or fissility. The estimation of shale represents almost ¾ or 70 percent of the sedimentary rock on the earth's crust.

In drilling through shale, one important problem is often encountered, which is the sticking of pipe or stuck pipe. Due to the absorption of water into the structure of the clay group. The rock layer that swells from absorbing water will expand the size of expanding as shown in Figure 2.6-2.8.

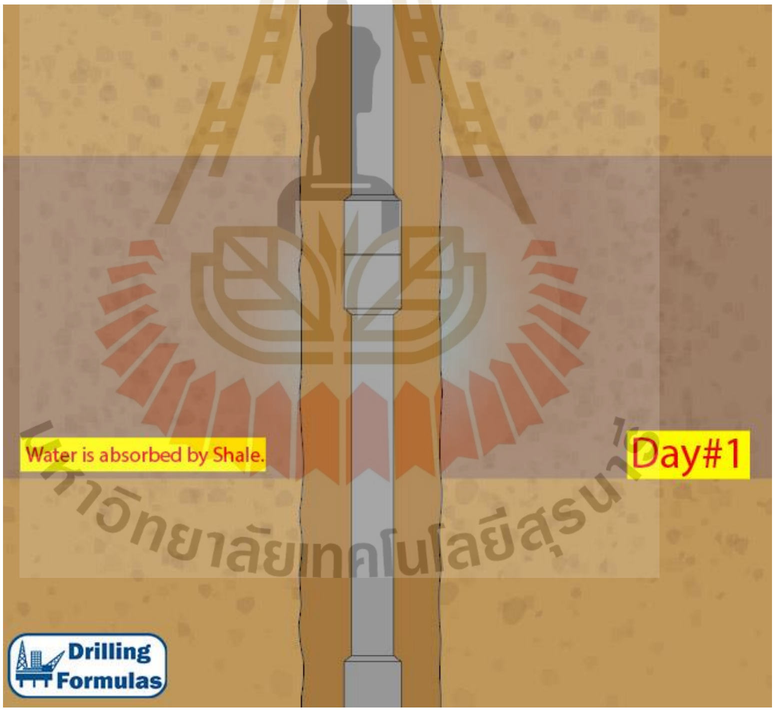


Figure 2.6 Day 1 # Water is absorbed by shale. (DrillingFormulas.Com, 2011)

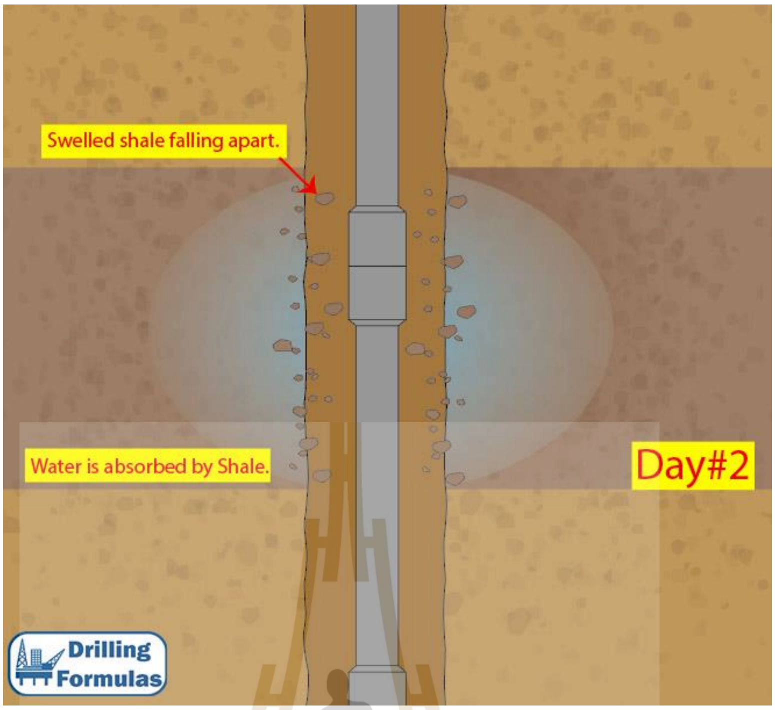


Figure 2.7 Day 2 # Shale swelling due to water and shale starts falling apart. (DrillingFormulas.Com, 2011).

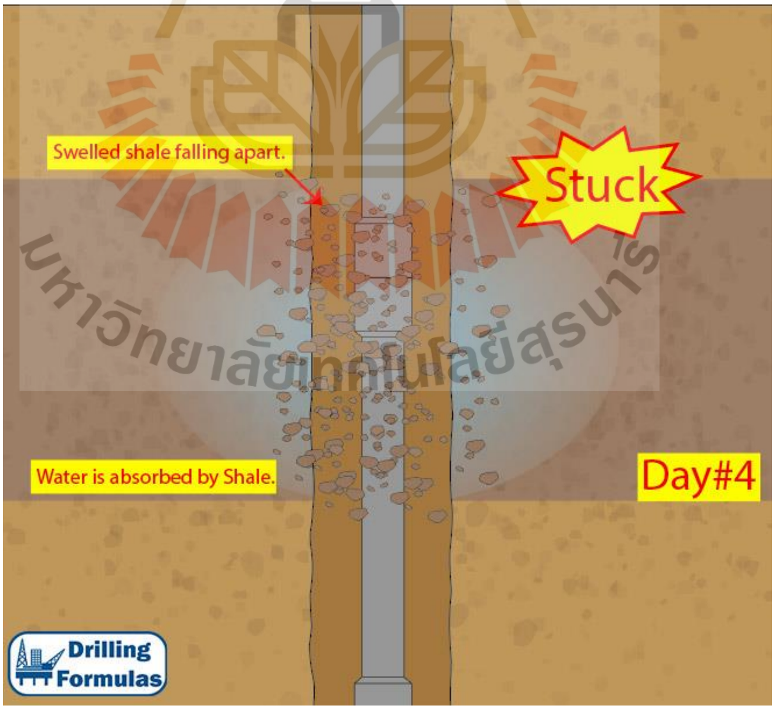


Figure 2.8 Day 4 # A lot of shale falls and causes stuck pipes. (DrillingFormulas.Com, 2011).

Shale is typically categorized into two types: effective shale and non-effective shale. Effective shale refers to the predominant presence of multilayer clays such as smectites (montmorillonite, bentonite) and illite. These clays exhibit significant cation exchange capacities (CEC). On the other hand, non-effective shale consists of minerals like kaolinite and chlorite, which have very low CEC. Shale poses challenges in oil and gas drilling wells, with one major issue being shale swelling. The absorption of water by clay minerals like montmorillonite can lead to stuck pipes and interpretive logging problems (Sutheera, 2017). Moreover, the presence of shale can introduce inaccuracies in calculating water saturation and porosity values from logs, especially in the case of effective shale. To address these concerns, X-ray diffraction (XRD) analysis is performed to determine the mineral composition, while X-ray fluorescence (XRF) techniques are utilized to analyze the elemental composition and identify the quantity and types of clay minerals in the tested samples.

2.4 Clay minerals

Clay minerals are composed of particles with small crystals and are classified into different groups based on their crystalline structure. Due to improper sorting in evaporite sedimentary environments, most sandstone reservoirs contain clay minerals. A significant portion of sedimentary sequences consists of clay minerals, which can originate from the following sources:

2.4.1) Clay minerals derived from older rocks and sediments.

2.4.2) Clay minerals are formed through the conversion and alteration of unstable minerals due to changes in environmental conditions, such as pH and temperature.

2.4.3) Clay minerals formed in situ, contributing to the composition of pore water.

There are hundreds of clay minerals categorized into five main groups based on their structure and composition: kaolinite and mica (illite), smectite (montmorillonite), chlorite, and vermiculite (Murray, 1991).

A group of aluminosilicate minerals consisting of a stack of silica sheets and alumina sheets, typically smaller than 2 μm. and can be divided in Figure 2.9

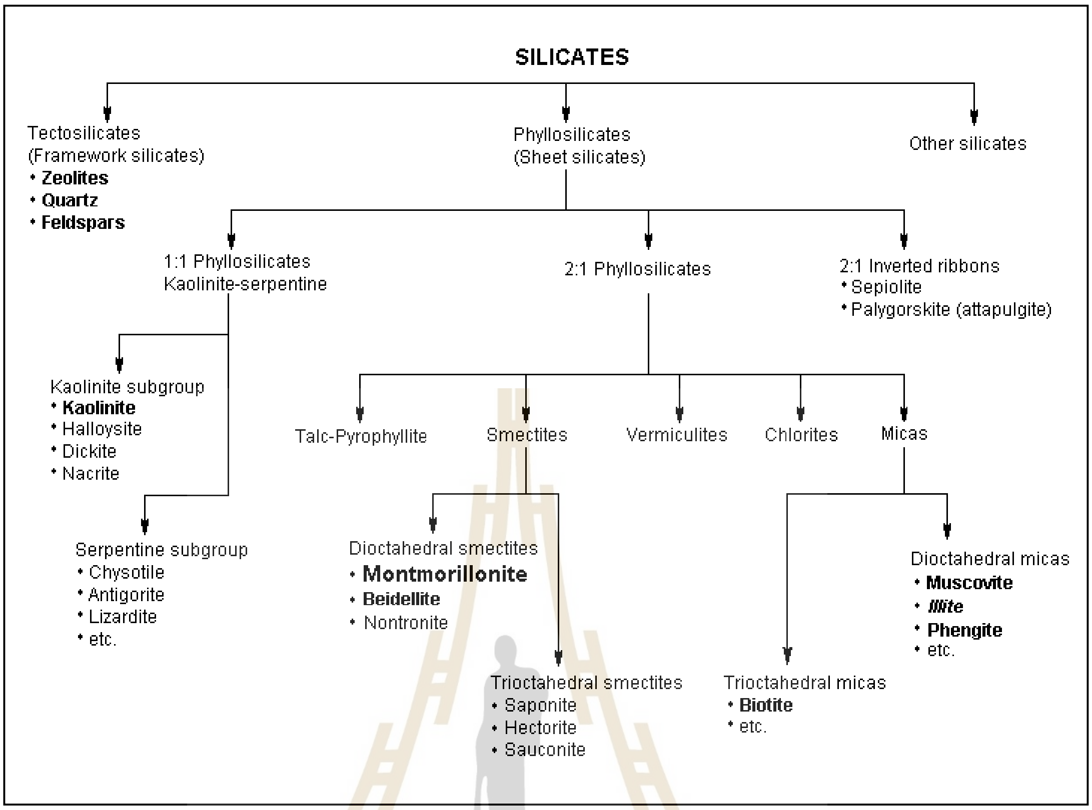


Figure 2.9 Silicate Mineral Group (Niwat, 2007)

2.4.1 Kaolinite

Kaolinite is a type of clay mineral that consists of two layers of clay with the structural formula $Al2O3{\cdot}2Si2O{\cdot}2H2O$. Its structure comprises a tetragonal silica sheet and an octahedral alumina sheet. Kaolinite particles are held together by hydrogen bonding, and the distance between the layers is approximately 2.76 Å. This hydrogen bond is strong enough to keep water molecules separated from the clay surface. As a result, kaolinite is considered a non-swelling clay and has a cation exchange capacity (CEC) ranging from 3 to 15 meq/100g (Murray, 1991; Kale, 2009).

High-grade clay, commonly known as China Clay or Kaolin, is used in various applications such as brick manufacturing, roof tile production, and ceramic pipes. It is also utilized for pottery making of all kinds. Additionally, it is used to make fire-resistant bricks for metal furnaces. In paper production, it is often added to increase weight and smoothness and improve the coating of the paper surface. Furthermore, it finds application in the rubber industry and as a material for refractories. Its use in the ceramic industry is due to its desirable properties. When wet, it can be molded into desired shapes, and upon heating, the water molecules evaporate, resulting in a solid and durable structure.

2.4.2 Chlorite

Chlorites are a group of phyllosilicate minerals commonly found in low-grade metamorphic rocks and altered igneous rocks. Greenschist, which forms through the metamorphism of basalt or other low-silica volcanic rocks, typically contains significant amounts of chlorite (Niwat, 2007).

Chlorite minerals exhibit a wide range of compositions, with magnesium, iron, aluminum, and silicon substituting for each other in the crystal structure. Examples include magnesium-rich clinochlore and iron-rich chamosite. Additionally, there are known species with manganese, zinc, lithium, and calcium. The extensive variation in composition results in significant differences in physical, optical, and X-ray properties. Furthermore, the range of chemical composition enables chlorite minerals to exist under a wide range of temperature and pressure conditions. As a result, chlorite minerals are commonly found in low- and medium-temperature metamorphic rocks, certain igneous rocks, hydrothermal rocks, and deeply buried sediments.

This mineral has chemical formula of $Si_4Al_4O_{10}(OH)_8$, molecule structure consists of sheets of silica and alumina sandwiched together (1:1 type clay) with hexagonal crystals. Connected in an unlimited plane Structural plates have a thickness of 7 A^0

Mineral properties: Bonds between crystals are hydrogen bonds. sticking together tightly causing gaps between the slabs to be narrow and unable to expand Minerals do not expand when wet or shrink when dry.

2.4.3 Illite

Illite is a hydrous mica and a 3-layer clay mineral with the structural formula $K \cdot Al_2(OH)_2(Al \cdot Si)_3(O_2OH_{10})$. The structure of illite is like that of montmorillonite. Water molecules, however, cannot be accommodated between illite layers due to their lack of an expandable network. The illite layer is formed by assembling an octahedral alumina layer between a tetrahedral silica layer.

In illite, an electrical deficiency created by silicon atoms being replaced with aluminum atoms is compensated by potassium ions. Illite has a cation exchange capacity (CEC) between 10 and 40 meq/100g (Murray 1991; Kale 2009). In some cases, potassium can be replaced by divalent cations such as calcium and magnesium when silicon substitution by aluminum is limited. These situations may also cause illite to swell, like montmorillonite.

Illite $(K_{1.33}(Si_{6.66}Al_{1.33})Al_4O_20(OH)_4$ is generally leaf-shaped or filamentous, resulting in the development of micro-intergranular pores. K in the recesses absorbs between the silica sheets, the mineral cannot expand and shrinkage. when wet and dry It has properties between kaolinite and smectite (Niwat, 2007).

2.4.4 Montmorillonite

Smectite, specifically montmorillonite, is a type of 3-layer clay mineral with the formula $(Mg{\cdot}Ca)\ O{\cdot}Al_2O_3{\cdot}5SiO_2{\cdot}NH_2O$. Montmorillonite is a component of smectite. The mineral group comprises two sheets of tetrahedral silica surrounded by octahedral alumina.

In the middle layer, magnesium and iron atoms can replace aluminum atoms, causing an electrical imbalance. Therefore, cations accumulate on the surface of smectite particles. It is possible for these cations to be monovalent or divalent. Montmorillonite's swelling level is determined by its cation exchange capacity (CEC). The CEC of smectite ranges from 60 to 150 meq/100g.

Chemical formulas are complex and uncertain. The stable formulation is pyrophyllite with the formula $Si_8Al_4O_20(OH)_4$ / $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$.

It consists of two silica sheets sandwiched by a sheet of alumina (2:1 type clay). The structure and recesses between the overlapping sheets are 9-21 A^0.

Mineral properties Because the bonds between crystals are not hydrogen bonds, but weak oxygen-oxygen linkages are formed. Water molecules and cations can easily infiltrate and absorb on the inner surface. Causes swelling and when the water is evaporated, the mineral shrinks (Niwat, 2007).

2.5 Principal of Clay Mineral Study

2.5.1 X-Ray Diffraction (XRD)

X-ray diffraction is a technique used for phase identification. It is suitable for analyzing both crystalline and non-crystalline materials, providing valuable information on the unit cell dimensions, intensity, and 2θ values of crystalline material.

In X-ray diffraction, a beam of X-rays is directed at a sample, and the scattered X-rays are measured as a function of the outgoing direction. Conventionally, the angle between incoming and outgoing beams is 2θ.

According to Bragg's Law as Equation 2.1, constructive interference (resulting in higher scattered intensity) occurs between charge-separated sheets separated by a distance d.

$$n \lambda = 2 d \sin \theta \tag{2.1}$$

Here n is an integer (1, 2, 3, ...), λ is the wavelength of the X-ray beam, and θ is half the scattering angle 2θ.

Even though real materials are more complex, there is a general relationship between the interparticle distances in samples and the angles at which the scattered intensity is highest. Accordingly, greater interparticle distances (d) correspond to smaller scattering angles (physics.upen, 2018).

An X-ray powder diffractogram shows peak positions where the X-ray beam has been diffracted by the crystal lattice. A unique set of d-spacings derived from this pattern can be used to identify minerals.

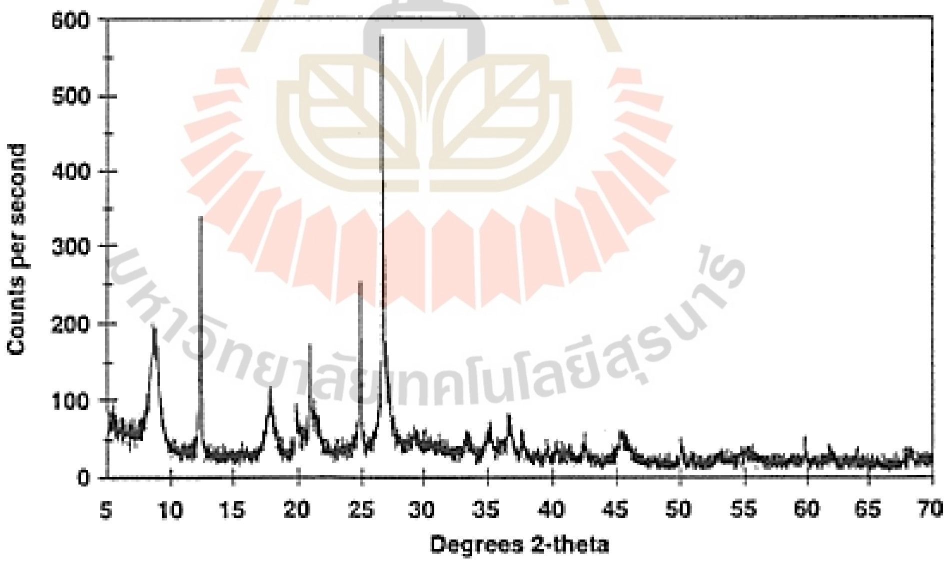


Figure 2.10 X-ray powder diffractogram (Serc.carleton, 2020).

2.5.2 X-ray Fluorescence (XRF)

The technique is used for elemental analysis. An X-ray beam is emitted into the sample by using the X-ray principle. A sample absorbs X-rays and spits out energy. The emitted energy or fluorescence will have an energy value depending on the type of element in the sample.

A detector used to measure the energy coming out of a sample allows us to identify the elements in the sample.

2.5.3 Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) scans surfaces with high-energy electrons to generate a variety of signals for solid specimens. It can be used to study objects as small as nanometers. An electron-sample interaction produces signals that provide information such as images of the surface, compositions, and properties of the surface, such as electrical conductivity.

Kaolinite is an uncharged dioctahedral layer clay mineral with the chemical formula $Al_2O_3\ 2SiO_2{\cdot}2H_2O$. Each layer consists of a tetrahedral silica sheet and an octahedral alumina sheet. An SEM analysis of kaolinite can be seen in Figure 2.11.

Illite is generally leaf-shaped or filamentous, resulting in the development of micro-intergranular pores (Figure 2.21a).

Chlorite, originating from biotite diagenetic transformation, usually shows schistose or planar schistose and presents very narrow slit pores among schistose layers (Figure 2.12b).

Figure 2.11 Scanning Electron Micrograph of low defect kaolinite from Kiralyhegy Hungary (Ray and Janos, 2004).

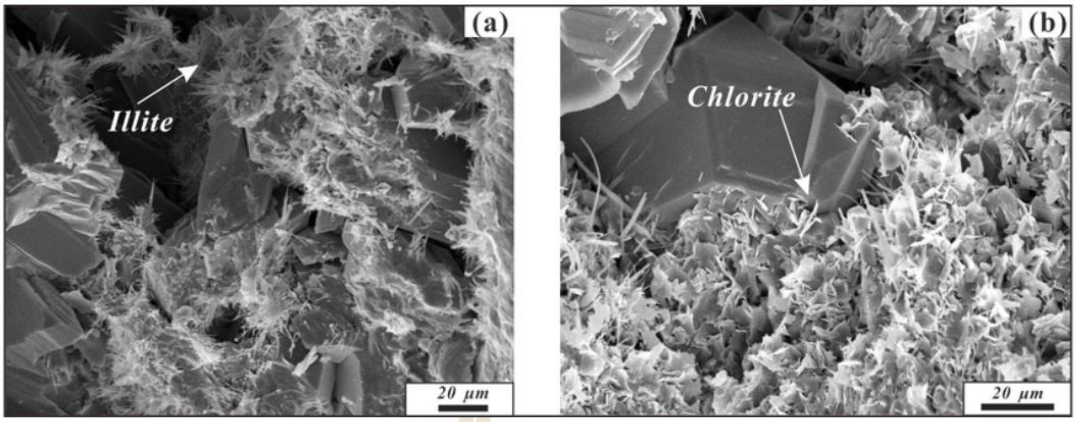


Figure 2.12 SEM image of illite (a) and chlorite (b) (Kun Yu, et al., 2019).

The Smectite group refers to a group of minerals known as phyllosilicates. Within this group, there are dioctahedral aluminum micas including the montmorillonite-beidellite series and the nontronite series, as well as Fe-smectite minerals. These minerals belong to the broader category of clay minerals. Smectite minerals exhibit a 2:1 structure with a general chemical formula of $M^{0.33+}$ $Al_2(Si_{3.67}Al_{0.33})O_{10}(OH)_2$, where M+ represents exchangeable cations such as Ca^{2+} and Mg^{2+} (Figure 2.13 and Figure 2.14). A scanning electron microscope (SEM) image of montmorillonite, a type of smectite mineral, is depicted in Figure 2.13.

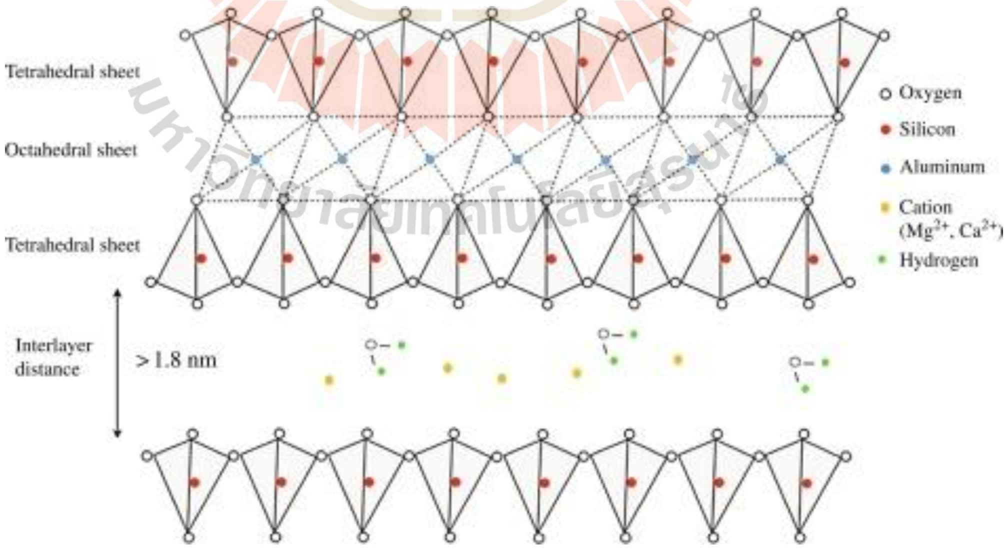


Figure 2.13 Smectite structure (Hamza and Mohamed, 2023)

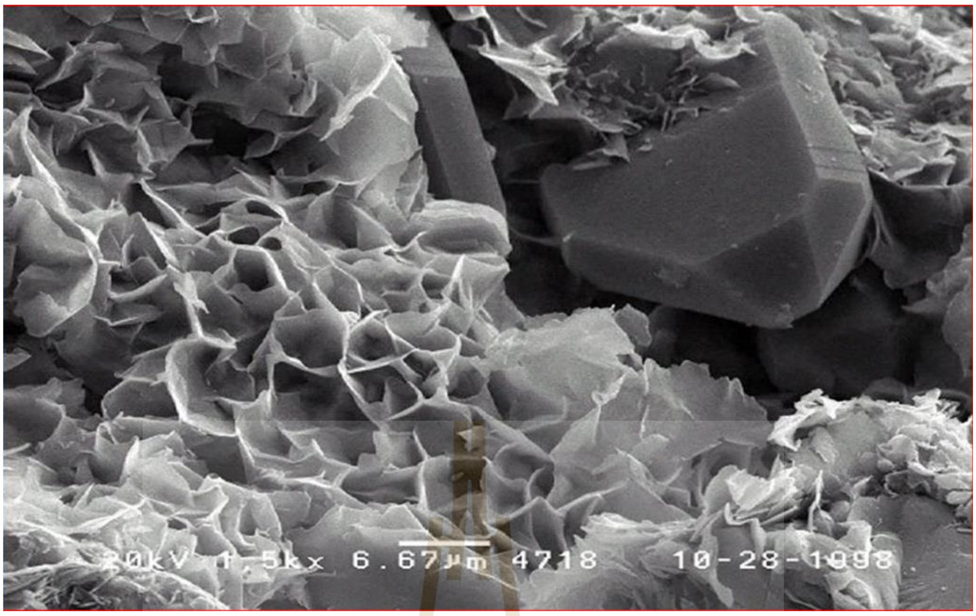


Figure 2.14 Sheets clusters and plate crystals of smectite visible by electron (SEM) microscopes (Haldar and Tišljar, 2014).

2.5.4 Logging Analysis

The purpose of drilling for geological exploration under the ground is to obtain Soil-rock samples (coring) This type of drilling is time-consuming. and cost a lot and drilling to collect and/or for logging. This type of drill penetrates quickly and loses. The cost is lower than the first type. but the information obtained from in-depth data indicates incorrectly that some units may not get rock fragments from the borehole. Surveys often collected samples and recorded other data at the same time by geologic method along with physics which is the additional cost from the geophysical technique. Using tools to measure the physical properties of rock such as measuring the density value. electrical resistance, wave speed, Gamma radiation, electric potential value, electrical conductivity, etc., by designing a probe that can be lowered into the borehole to the bottom of the hole. with the principle that if they are a formation of different types. It has physical properties (density, electrical resistivity, wave speed, Gamma radiation, electric potential, conductivity value, etc. are different). Most of the probes are installed inside the energy source and machine measurement (detector) and in making data recording while pulling the probe up from the bottom through the hole. Logging will record data. Then bring the data Interpret the geological conditions below the surface.

The gamma-ray log is a widely utilized method to determine lithologies by assessing the radioactivity of rocks. Naturally occurring radioactive materials (NORM) encompass elements such as uranium, thorium, potassium, radium, and radon, as well as the minerals that host them. While there is typically no direct relationship between specific rock types and gamma-ray intensity, a significant overall correlation exists between the content of radioactive isotopes and mineralogy. Logging tools have been specifically designed to detect and measure the gamma rays emitted by these elements, enabling the interpretation of lithology based on the collected data (Petrowiki, 2015)

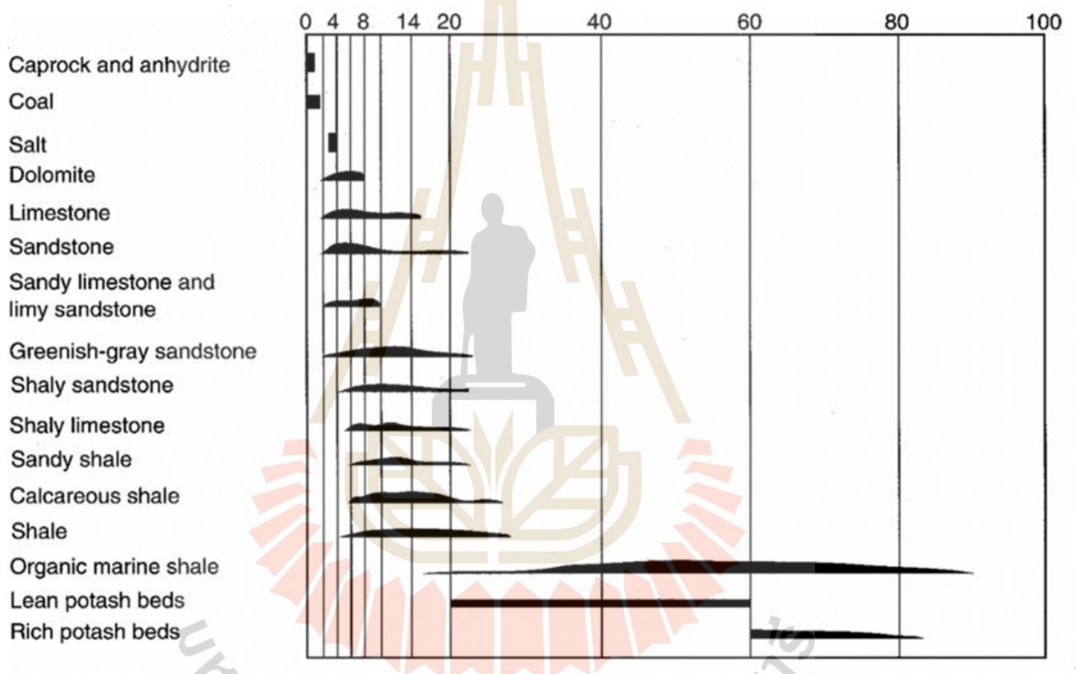


Figure 2.15 Relative radioactivity level for various rock types (Petrowiki, 2015).

Passive gamma ray devices are considered the simplest tools in terms of conceptual design. They do not require a radiation source and typically feature only one detector. These devices have a range of applications, from basic gross gamma-ray counters used for shale and bed-boundary delineation to more advanced spectral devices employed in clay typing and geochemical logging. Despite their apparent simplicity, these tools can be influenced by various boreholes and environmental factors, such as the presence of naturally radioactive potassium in drilling mud, which can easily introduce confounding effects.

In rocks, the primary radioactive isotopes are potassium-40, and the isotopes are associated with the decay series of uranium and thorium. Figure 4 illustrates the distribution of energy levels associated with each of these isotopic groups when they reach equilibrium. Potassium-40 (K40) emits a single gamma ray with an energy level of 1.46 MeV as it undergoes a transformation into stable calcium. On the other hand, thorium (Th) and uranium (U) decay through a sequence of radioactive daughter products, resulting in a variety of energy levels. Conventional gamma ray tools measure a broad spectrum of energy, encompassing the primary peaks as well as lower-energy daughter peaks. As depicted in Figure 2.15, the total count can be significantly influenced by the lower-energy decay radiation, which can dominate the overall measurement.

2.5.5 Drill Cuttings

The samples of rock fragments were brought up by the mud stream and examined by recording well logs. These samples are used for comparison with important data such as wireline logs, and special geological, geophysical, or engineering analyses. Cuttings are small in size and are of great importance for data analysis.

2.6 Previous Study

Drilling cutting samples of FA-MS-61-95 well from Mae Soon Oil field were prepared to be 63 microns of particle size to be analyzed with XRD. This study result conducted on cutting samples from this well revealed four clay minerals: montmorillonite, illite, kaolinite, and chlorite. The swelling of shale in this well is predominantly caused by montmorillonite. Furthermore, the montmorillonite quantity was stable or slightly increased with depth. In general, shale contains minerals that affect swelling, such as montmorillonite. Mineral content in montmorillonite ranges between 4.90 and 6.80 percent based on rock samples from wells FA-MS-61-95. The illite content ranges from 15.8 to 20 percent, the kaolinite content is between 11.00 and 14.13 percent, and the trend of montmorillonite ore is relatively stable or slightly increasing with depth. It is found that kaolinite tends to increase as the depth increases, and illite tends to decrease as the depth increases. The trend lines of clay content in each depth range are shown in Figure 2.16.

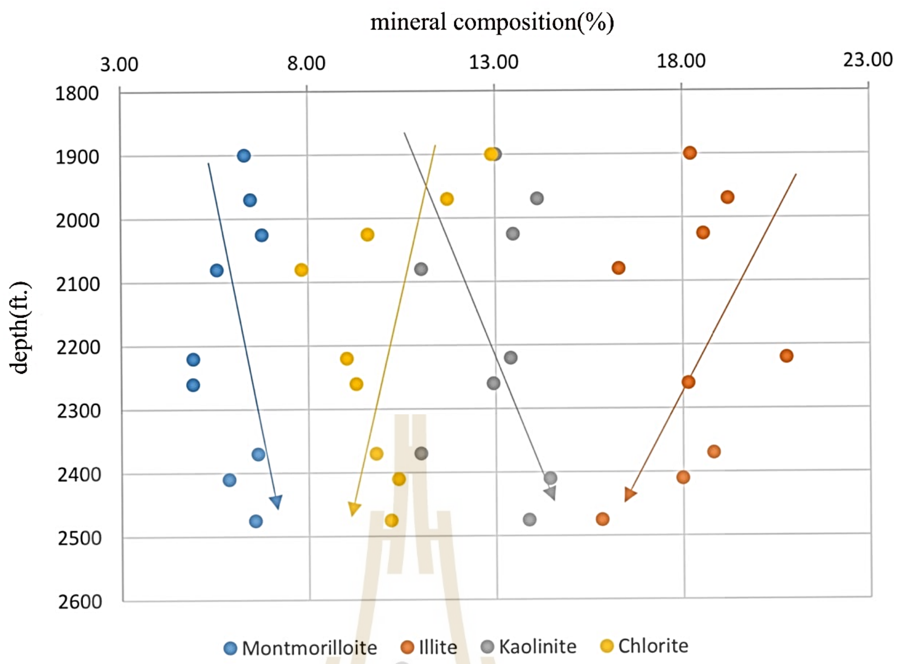


Figure 2.16 Clay mineral with depth from FA-MS-61-95 well (Phiriya-anuphon, 2017).

A study by Maghrabi et al. (2013) examined the challenge of ANN models. An XRD analyzer is used to determine the mineral composition of co-shale, and the linear swell meter (LSM) method is used to predict the tendency of shale swelling. It appears that the linear swelling rate measurement for the shale body in this study is consistent with this result.

Razak Ismail et al, (2015) focused on investigating the characteristics of ester oil-based drilling fluid systems by utilizing a blended mixture of ester and synthetic mineral oil. The continuous oil phase of the drilling fluid comprised Malaysian palm oil ester derivatives (methyl laureate ester or isopropyl laureate ester) blended with commercially available synthetic mineral oil. The addition of mineral oil to the ester-based drilling fluid systems aimed to mitigate the problem of alkaline hydrolysis. However, it was observed that the mixture of methyl laureate ester with mineral oil exhibited instability under high-temperature alkaline hydrolysis. On the other hand, the system with a blend of isopropyl laureate and mineral oil showed promising stability against the hydrolysis process, even at temperatures up to 250°F. Nevertheless, the introduction of mineral oil into the isopropyl laureate ester-based system appeared to destabilize the drilling fluid by weakening the intermolecular bonding of the ester molecules, leading to a significant increase in the rheological properties.

Xiangchao Shi et at., (2019) studied on the impact of using sylvile (KCl) as an inhibitor on the expansion of clay minerals. They used two types of clay specimens, labeled as a and b, and investigated the effects of soaking them in KCl solutions with concentrations of 2%, 4%, 6%, and 8% for 24, 48, 72, and 96 hours (Figure 2.17). The results showed that an increase in the concentration of KCl helped inhibit the swelling of the clay minerals.

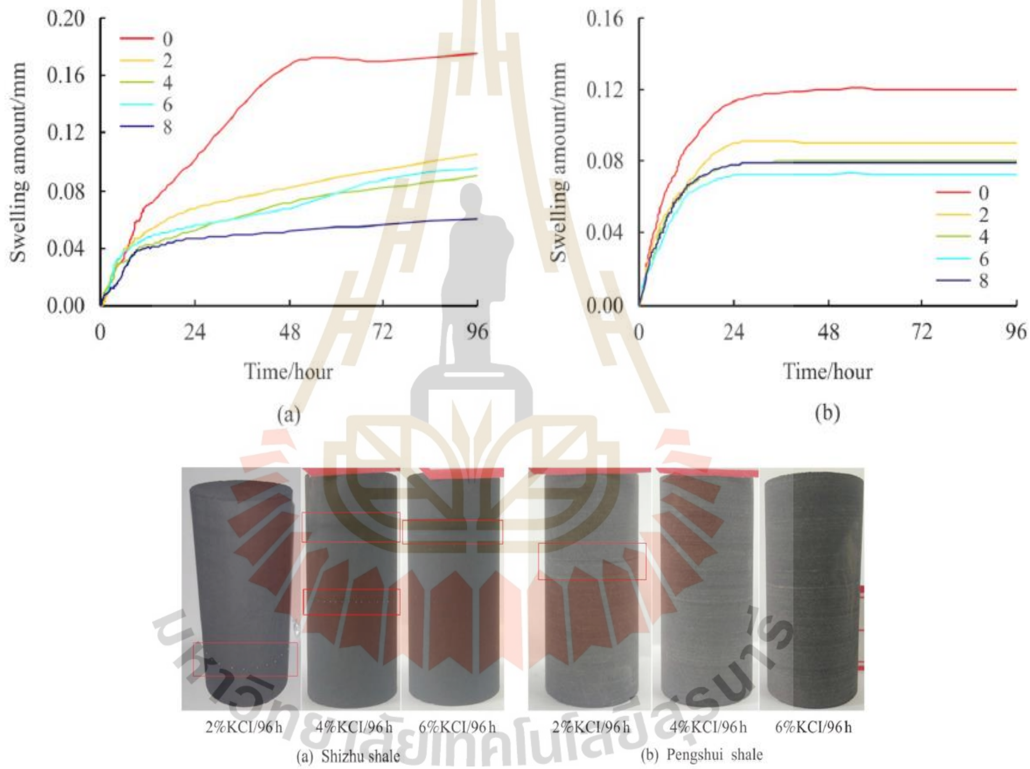


Figure 2.17. Swelling of shale samples with water and sylvite (KCl) imbibition (Xiangchao Shi et at., 2019).

CHAPTER III
RESEARCH METHODOLOGY

3.1 Sample Collection

Forty-seven samples from FA-SS-35-04 well located in Fang Basin were systematically collected from vertical lithology during the exploration and development of oil and gas. The sample consists of 10 samples of Mae Fang Formation and 39 samples of Mae Sod Formation (15 samples of Upper Unit A, 11 samples of lower unit A, 5 samples of Unit B, and 8 samples of Unit C).

3.2 Methodology

The methodology of this study as shown in Figure 3.1 includes physical analysis to describe petrographic analysis, and chemical analysis (X-Ray diffraction; XRD analysis, X-Ray Fluorescence; XRF) analysis, and Scanning Electron Microscope (SEM) analysis).

The petrographic analysis can be used to indicate the depositional environment (color, grain size, composite). The XRD, XRF analysis, and SEM analysis can identify the composition of minerals, elemental association, and morphology, respectively. Furthermore, physical and chemical analysis can be used to indicate the problem zone by correlation with logging data.

3.2.1 The X-ray Diffraction (XRD) Analysis

Thirty-nine cutting samples were obtained from the FA-SS-35-04 well, 8 samples from Mae Fang Formation and specifically from the Mae Sod Formation. These samples consist of 15 samples from Upper Unit A, 11 samples from Lower Unit A, 5 samples from Unit B, and 8 samples from Unit C.

All cutting samples from the FA-SS-35-04 well were prepared and ground using a ball mill machine (Figure 3.1). The mineral composition of the shale was then tested at Suranaree University of Technology. The mineral composition analysis was conducted using an X-ray Diffraction Diffractometer-D8 (XRD-D8) by scanning from 2° to 60°2Θ at a rate of 0.02° per minute, with a Cu X-ray tube (Figure 3.3). The XRD data obtained was subsequently analyzed using the Topaz program. Forty-seven cutting samples were obtained from the FA-SS-35-04 well, specifically from

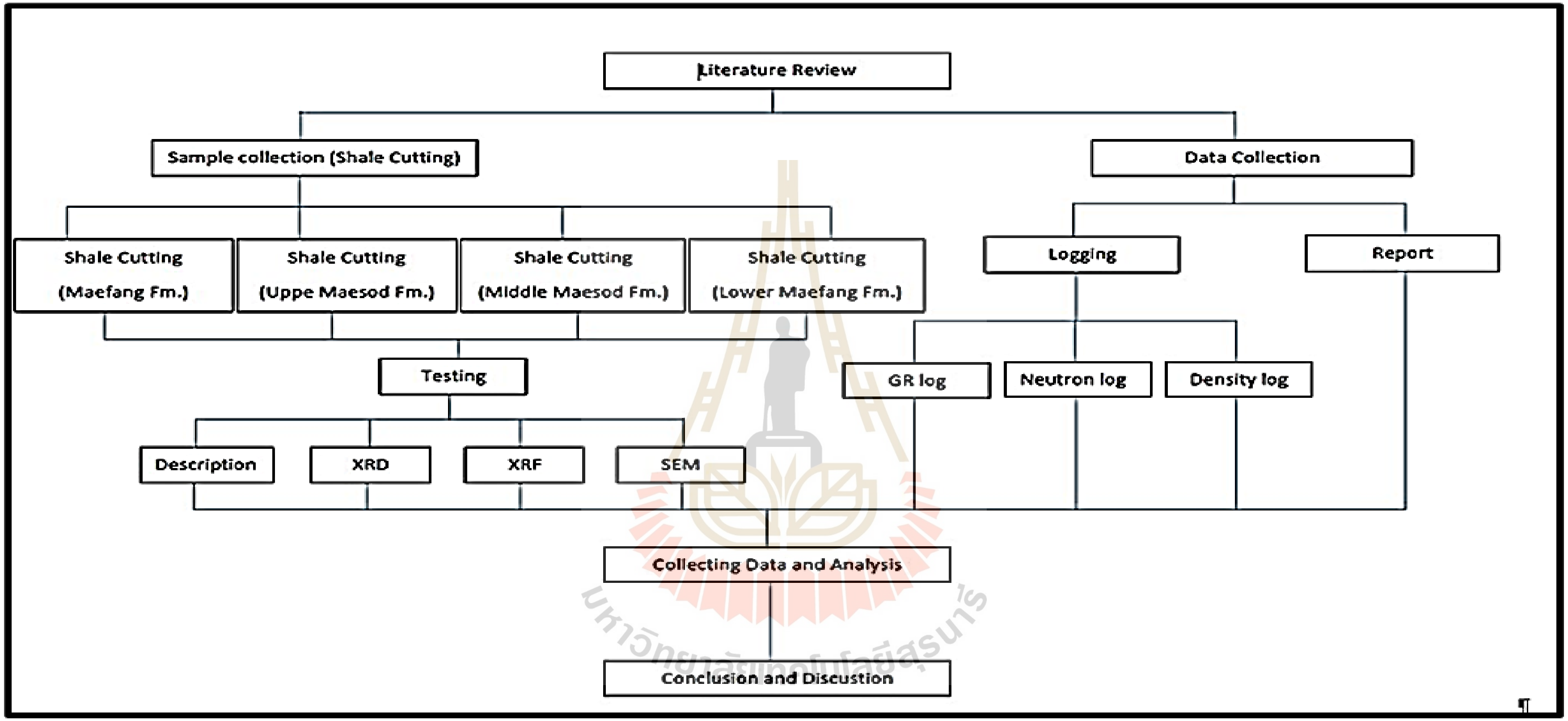


Figure 3.1 Flowchart represents the research methodology.

the Mae Sod Formation. These samples consist of 15 samples from Upper Unit A, 11 samples from Lower Unit A, 5 samples from Unit B, and 8 samples from Unit C.

Figure 3.2 Ball Mill machine.

Figure 3.3 Powder X-ray Diffraction (XRD)

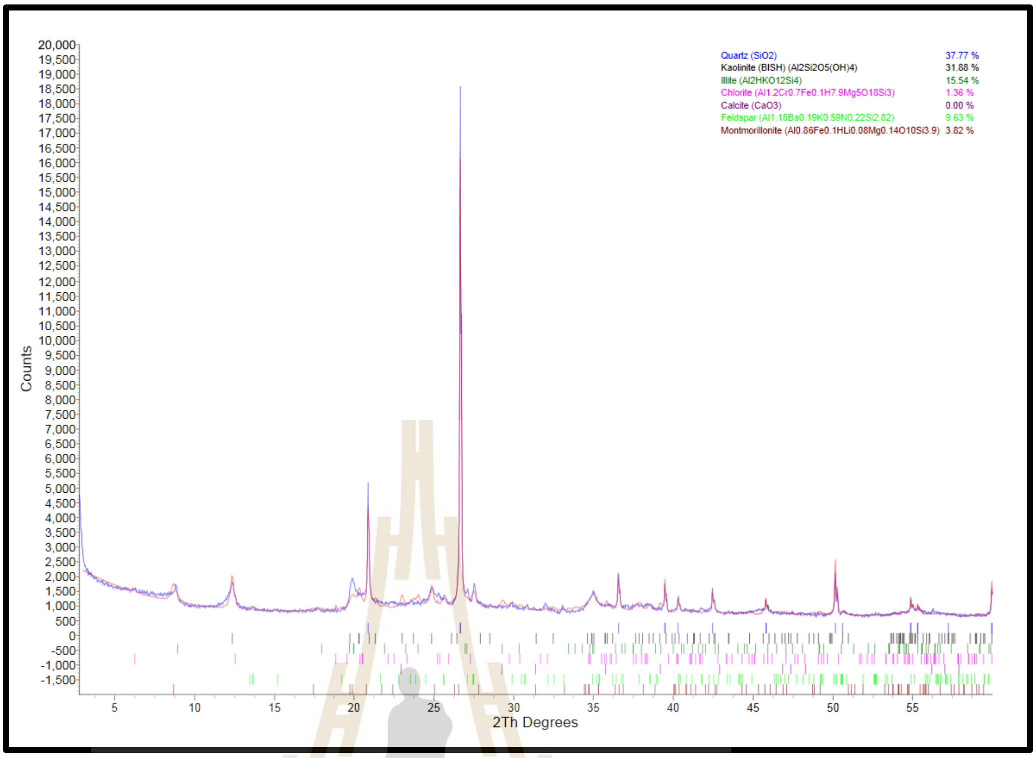


Figure 3.4 The results of mineral interpretation.

3.2.2 The X-Ray Fluorescence (XRF) Analysis

X-ray fluorescence is a technique for analyzing the type of elements and the in the sample. Based on the principle that the electrons in the orbits of the atom Shift from a high-energy tier to a lower-energy tier. and emits energy in the form of X-rays with specific energy (characteristic X-ray) of each element XRF analysis is a chemical element analysis that is done by grinding the samples into the XGT-5200 X-Ray (Figure 3.5). analytical microscope and translation through the computer. The X-ray source is an Rh X-ray tube, 50 kV/ 1 mA, Mono-capillary guide tubes and the Fluorescence detector is Peltier cooled Silicon Drift Detector (SDD), Energy 0-40 keV, Elements detected 11Na to 92U. The result will show a percentage of chemical elements by graph according to the periodic table as shown in Figure 3.6. and data can be saved in pdf format.

Figure 3.5 X-ray Fluorescence (EDXRF) Horiba XGT-5200 X-ray Analytical.

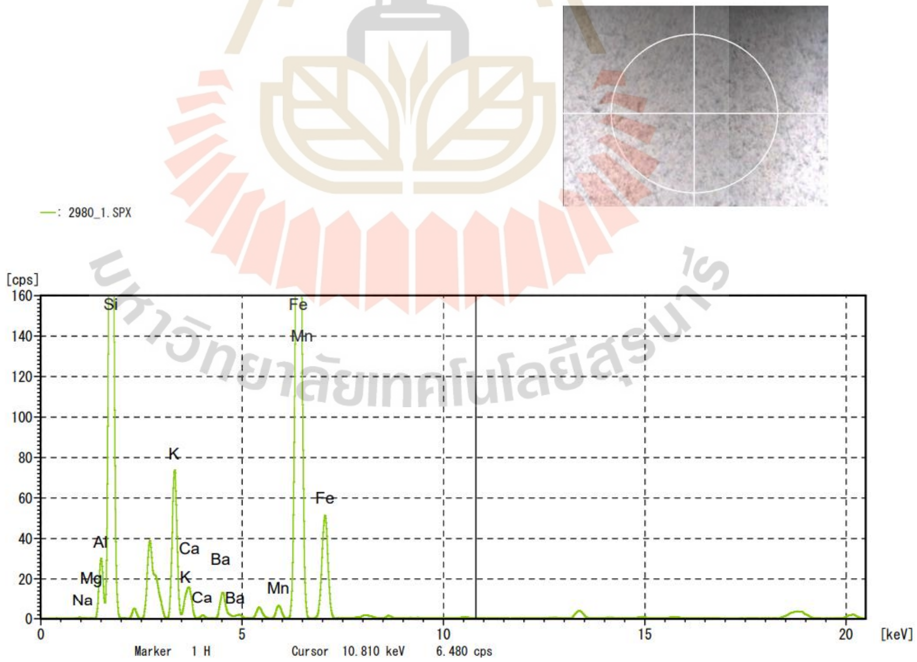


Figure 3.6 Sample screen while showing XRF translation results.

3.2.3 Scanning Electron Microscope (SEM) Analysis

Scanning electron microscope (SEM) is a method used to sample specimens prepared using a high-resolution microscope to see sheets of clay minerals for scanning morphology microstructure of high montmorillonite samples.

Figure 3.7 JEOL JSM-6010LV Scanning Electron Microscope (Cste.sut, n.d.).

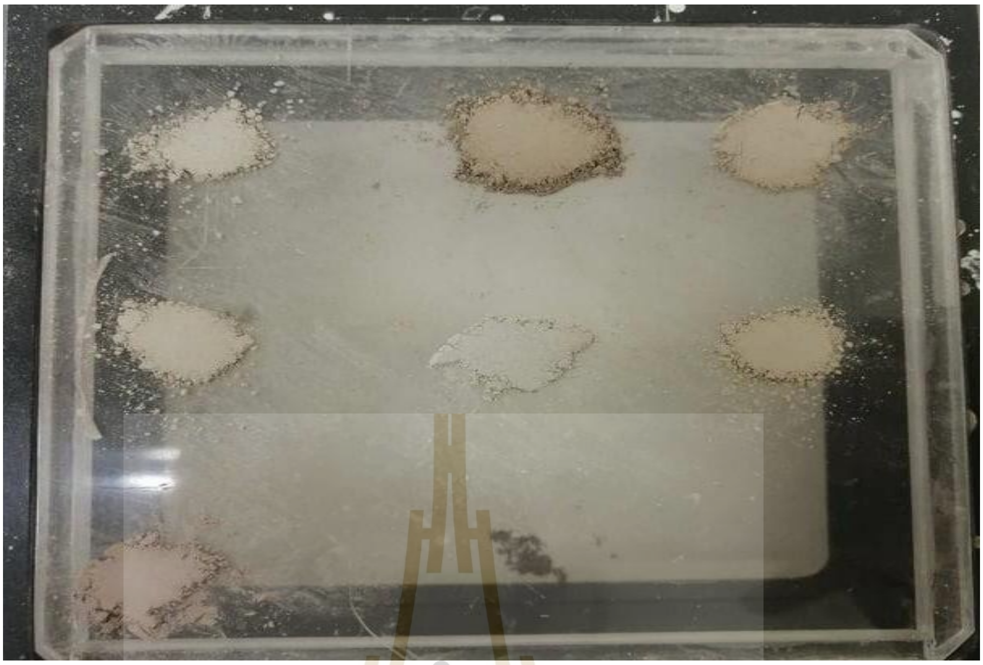


Figure 3.8 Sample prepared for XRF testing.

3.2.4 Shale Volume

One of the clay quantificational predictions is shale volume calculation using a method of measuring naturally occurring gamma ray radiation to characterize the rock of sediment in a borehole from Gamma ray log. The shale volume is calculated using the linear method (Adeoti et al., 2009) as the following Eq. (3.1).

$$Vsh = (GRlog - GRmin) / (GRmax - GRmin) \tag{3.1}$$

Where, the GRlog = gamma-ray of the interesting zone, GRmin = minimum value of gamma-ray log, and GRmax = maximum value of the Gamma-ray log.

3.2.5 Density Log

The density tool has the source of radiation that will be emitted through the formation to the detector for interpretation of the result as a bulk density in unit of g/cc as shown in Figure 3.9 and Figure 3.10, called the density log according to the depth of the rock layer.

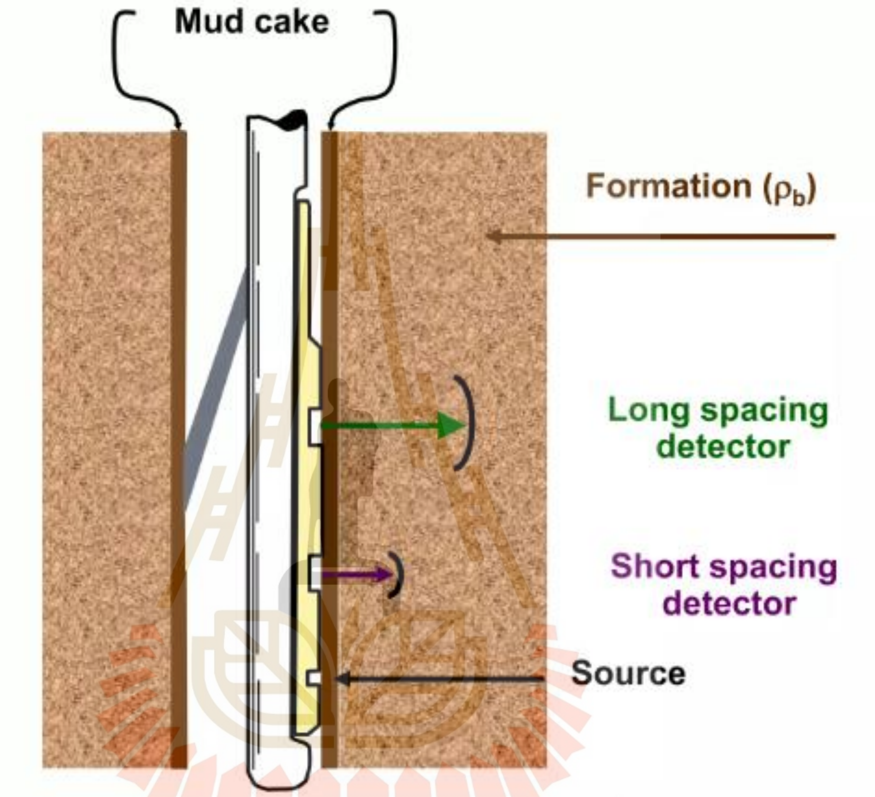


Figure 3.9 Density log (Laishram, 2014).

3.2.6 Neutron Log

Neutron porosity log principle based on emit a neutron particle away from the source Neutron particles are released with speed, it spreads out in the soil-rock. Neutron particles will stop moving or moving very slowly when colliding with hydrogen atoms because they have the same mass weight. Therefore, if the rock has porosity and water, there are many hydrogen atoms. The emitted neutron particles are less detectable. Absence of hydrogen atoms Interpretation If interpreted by considering Density porosity log, Neutron porosity log and Gamma-ray log together will result in Translate results more accurately and reliably.

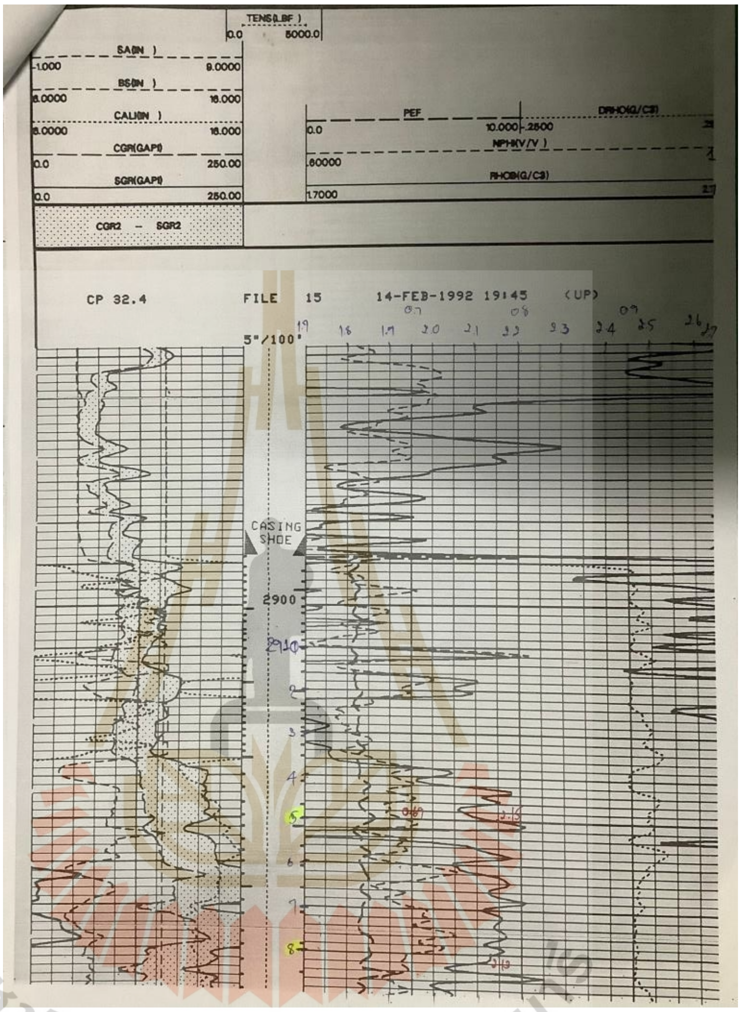


Figure 3.10 Logging Data.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter consists of Mae Fang Formation sample and Mae Sod Formation Samples result analysis to study mineral composition and elemental composition to identify swelling shale zone correlate with logging data.

4.1 Sediment Interpretation of Cutting Samples

The chapter shows the results of laboratory experiments and data collected, including physical analysis, chemical analysis, and logging data. Samples were tested and analyzed at the Suranaree University of Technology. The results and data of samples from the FA-SS-35-04 well are revealed below.

All samples were physically tested by Petrology and SEM. All samples were divided into two formations including Mae Fang Formation (Table 4.1-4.2) and Mae Sod Formation (Table 4.3-4.8) according to their characteristics.

4.1.1 Mae Fang Formation Cuttings

The results of the sample analysis were based on the cutting description. All cutting samples obtained from the Mae Fang Formation, spanning from 120 to 2,500 feet, were studied for their physical properties, as depicted in Figure 4.1.

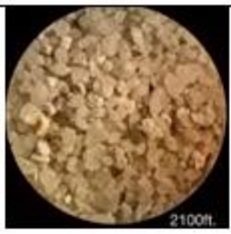
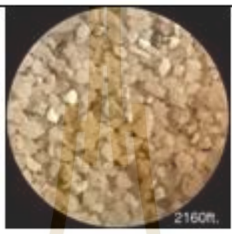
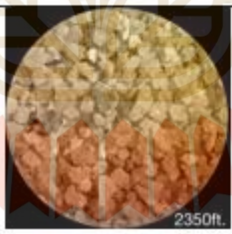
The uppermost section, representing a thickness of 900 feet, mainly consists of gravel-sand clay with a small amount of coal present. The gravel exhibits a light gray-to-gray coloration and is characterized by a very coarse to coarse-grained sand texture. The clay component appears gray. Beneath the upper part of the Mae Fang Formation, there is an approximately 1,600 feet thick sequence of very coarse-grained sand. This particular layer of sand displays a color range from light gray to dark gray.

.

Table 4.1 Cutting samples characteristics and description from depths of 870, 960, 1350, 1830, 2100, 2160, 2260, and 2350 feet of Mae Fang Formation.

No.	Formation	Depth (ft)	Cutting samples	Description
1	Mae Fang Formation	870		• 8 Samples • Depth: ~2500 feet • Formation: Mae Fang • Age: Pleistocene – Recent (2.58 Ma- Recent • Lithology: The gravel is light gray to gray very-coarse to coarse grained sand, mainly gravel-sand, round • Color: Light gray to gray • Environment Deposition: Fluvial deposit
2		960		
3		1350		
4		1830		

Table 4.2 Cutting samples characteristics and description from depths of 870, 960, 1350, 1830, 2100, 2160, 2260, and 2350 feet of Mae Fang Formation (Continue).

5	Mae Fang Formation	2100		
6		2160		
7		2260		
8		2350		

4.1.2 Mae Sod Formation Cuttings

Based on their characteristics, samples below 2,500 feet were classified as part of the Mae Sod Formation. This formation consists of three sub-units, namely sub-Unit A, sub-Unit B, and sub-Unit C.

Sub-Unit A spans from 2,500 to 3,980 feet. It is divided into an upper part and a lower part. The upper part of the deposit consists of gray to dark gray sediments. This portion of the sandstone is predominantly medium- to very coarse-grained and well-sorted sandstone. The lower part of sub-Unit A, it consists of dark gray, black, and brown shale, with fine-grained sandstone as well.

Sub-Unit B ranges from 3,980 to 5,800 feet. It consists of an extremely thick layer of dark-gray shale, along with fine-grained sandstone and coal.

Sub-Unit C is located from 6,800 to 9,200 feet and represents the lower part of this formation. Black shale alternates with sandstone and coal bed interbedded within it. This sub-unit is characterized by red and gray colors. A fine- to very coarse-grained sandstone is typically found within this layer.

Table 4.3 Cutting samples characteristics and description from depths of 2860, 2790, and 2820 ft.

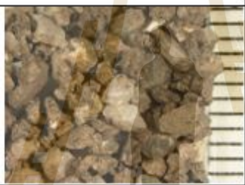
No.	Mae Sod Formation		Cutting samples	SEM	Description
	Sub Unit	Depth (ft.)			
9	Upper Unit A	2680			• 15 samples • Depth: 2,500 to 5,800 feet • Formation: Mae Sod • Age: Early Miocene – Late Pliocene (23Ma – 2.58Ma)
10		2790			
11		2820			

Table 4.4 Cutting samples characteristics and description from depths of 2950, 2980, 3000, 3030, 3080, 3150, 3180, and 3220 ft.

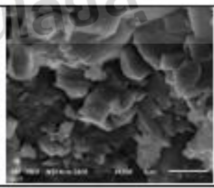
12		2950			• Color: gray to dark gray and brown color • Lithology: Shale, Coarse grained sand Composed of dark gray and brown coarse-grained sand • Environment Deposition: Marginal lacustrine • Petroleum system: Reservoir, Seal trap
13		2980			
14		3000			
15		3030			
16		3080			
17		3150			
18		3180			Light gray shale, gray to brown fine-grained sand
19		3220			

Table 4.5 Cutting samples characteristics and description from depths of 3220, 3240, 3270, 3930, 2980, 4020, 4110, 4140, and 4170 ft.

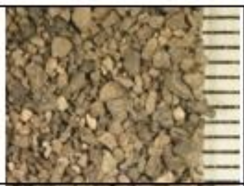
20		3240			
21		3270			
22		3930			
23		3980			
24	Lower Unit A	4020			• 11 samples • Depth: 2,500 to 5,800 feet • Formation: Mae Sod • Age: Early Miocene – Late Pliocene (23Ma – 2.58Ma) • Color: gray to dark gray and brown color • Lithology: Shale, Light gray to dark shale , gray to brown fine-grained sand
25		4110			
26		4140			
27		4170			

Table 4.6 Cutting samples characteristics and description from depths of 4360, 4470, 4500, 4640, 4740, 4840, 4940, and 5830 ft.

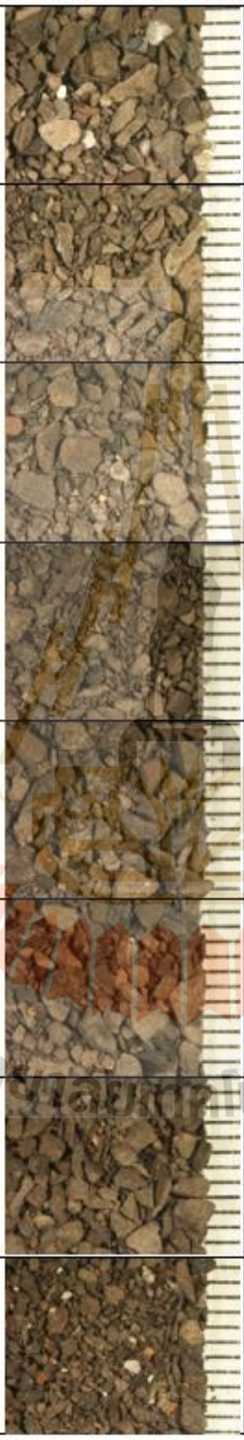
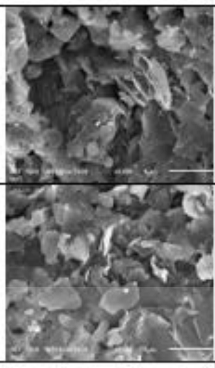
28		4360			• Environment Deposition: lacustrine • Petroleum system: Reservoir, Seal trap
29		4470			
30		4500			
31		4640			
32		4740			
33		4840			
34		4940			
35	Unit B	5830			• 5 samples • Depth:5,800 to 6,800 feet

Table 4.7 Cutting samples characteristics and description from depths of 6160, 6280, 6450, 6700, 7110, and 7300 ft.

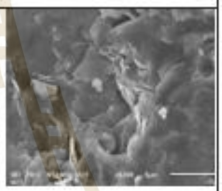
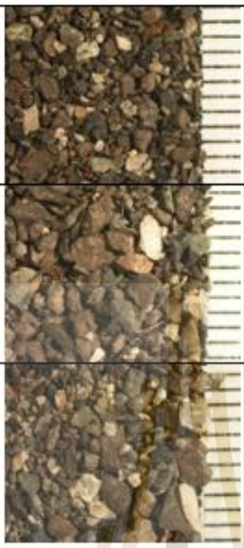
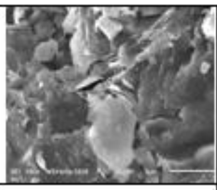
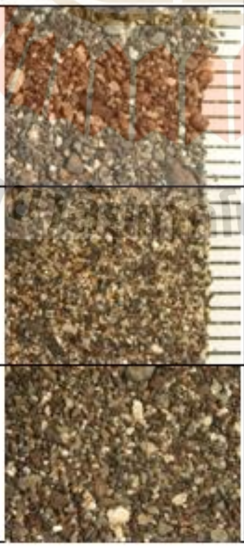
36		6160			• Formation: Mae Sod • Age: Oligocene (33.9Ma – 23Ma) • Color: gray to dark • Lithology: thick dark-gray shale, fine-grained sandstone Oxidation, gray to dark shale, gray to brown of fine to coarse grained sand. • Environment Deposition: low-energy conditions of freshwater paleo-lake • Petroleum system: Source rock
37		6280			
38		6450			
39		6700			
40	Unit C	7110			• 8 samples • Depth: 6,800 to 9,200 feet • Formation: Mae Sod • Age: Late Eocene or Older
41		7300			

Table 4.8 Cutting samples characteristics and description from depths of 8120, 8680, 8930, 8830, and 9150 ft.

42		8110			(56Ma – 33.9Ma or Older) • Color: generally red and gray • Lithology: part of sandstone and a coal bed interbedded with black shale, Dark grained of shale, dark to brown fine to coarse grained sand, trace of coal. • Environment Deposition: marginal lacustrine .
43		8120			
44		8680			
45		8730			
46		8830			
47		9150			

4.2 Chemical analysis

4.2.1 Mineral Composition

The result of mineral composition and elemental composition on a variety of depths is shown in Table 4.9, and Figure 4.1 to 4.3. The study is especially focused on montmorillonite which causes shale swelling (Steinmetz, 2009).

Table 4.9 Mineral compositions of Mae Sod Formation from FA-SS-35-04 well in San Sai Oil Field.

formation	Unit	depth(ft.)	Mineral compositions (%)							Average value
			Q	K	Il	Ch	Ca	Feld	Mon	
Mae Fang	-	870	94.05	0.12	0.18	0.16	0.04	4.54	0.92	Q = 87.92%
		960	88.61	0.02	0.54	0	0.03	8.28	2.55	K = 0.11%
		1350	88.34	0.31	0.58	0.17	0.06	9.45	1.09	Il = 0.42%
		1830	89.91	0.16	0.5	0.04	0.03	7.64	1.72	Ch = 0.11%
		2100	84.51	0.23	0.37	0.18	0.08	12.27	2.37	Ca = 0.08%
		2160	84.74	0.06	0.45	0.05	0.14	12.86	1.7	Feld = 9.69%
		2260	85.85	0	0.5	0.21	0.1	11.22	2.12	Mon = 1.68%
		2350	87.35	0	0.26	0.1	0.13	11.22	0.93	
Mae Sod	upper unit A	2680	63.85	17.04	6.93	0.95	0.00	8.44	2.42	Q = 63.99%
		2790	66.30	16.24	6.89	0.91	0.00	7.62	2.05	K = 14.52%
		2820	82.20	5.05	1.75	0.16	0.02	10.26	0.59	Il = 7.04%
		2950	70.78	12.78	5.19	0.67	0.01	8.77	1.69	Ch = 0.63%
		2980	53.94	19.57	10.38	0.78	0.00	12.30	3.03	Ca = 0.02%
		3000	68.74	9.61	6.40	0.36	0.00	13.91	0.98	Feld = 11.75%
		3030	70.76	8.32	4.77	0.23	0.00	14.96	0.96	Mon = 2.02%
		3080	47.38	20.76	11.08	0.93	0.00	17.49	2.36	
		3150	75.22	6.53	6.26	0.00	0.00	9.48	2.51	
		3180	37.41	31.27	13.05	1.58	0.00	12.52	4.16	
		3220	77.44	8.19	3.56	0.30	0.21	9.45	0.85	
		3240	68.48	10.68	5.54	0.55	0.05	13.50	1.20	
		3270	64.54	12.76	7.26	0.49	0.02	13.31	1.62	
		3930	53.06	21.22	9.83	1.02	0.00	11.54	3.34	
		3980	59.75	17.77	6.66	0.59	0.00	12.72	2.51	
	Lower unit A	4020	62.11	16.46	6.67	0.99	0.00	11.03	2.75	Q =41.62%
		4110	46.67	26.47	8.63	1.24	0.00	12.73	4.25	K = 23.80%
		4140	46.67	26.47	8.63	1.24	0.00	12.73	4.25	Il = 11.53%
		4170	51.01	24.33	8.78	1.43	0.00	9.82	4.62	Ch = 1.33%
		4360	41.72	31.78	10.52	1.85	0.00	8.26	5.86	Ca = 8.05%
		4470	28.38	37.65	14.16	1.58	0.00	10.11	8.12	Feld = 9.04%
		4500	29.43	31.80	14.35	1.92	5.16	10.16	7.17	Mon = 4.96%
		4640	43.79	21.56	10.98	1.46	10.90	6.48	4.84	
		4740	36.14	16.23	17.66	1.75	19.51	3.91	4.79	
		4840	39.21	16.07	14.10	0.68	19.88	5.74	4.31	
		4940	32.67	12.94	12.40	0.48	33.09	4.77	3.65	
	Unit B	5830	19.93	15.73	10.51	0.56	45.36	4.91	2.99	Q = 28.37%, K = 13.68%
		6160	17.97	11.93	14.13	0.46	45.44	4.72	5.36	Il = 12.31%, Ch = 0.56%
		6280	23.36	12.52	8.48	0.68	46.57	4.22	4.17	Ch = 0.56%, Ca = 8.05%
		6450	39.58	10.36	11.84	0.47	27.27	5.42	5.06	Feld = 5.12%, Mon = 5.30%
		6700	41.03	17.84	16.60	0.63	8.70	6.31	8.90	
	Unit C	7110	29.17	33.20	14.60	1.35	0.42	13.16	8.10	Q = 54.96%
		7300	72.38	10.18	7.01	0.90	0.00	5.33	4.20	K = 17.70%
		8110	47.21	19.04	14.63	1.41	0.10	9.54	8.06	Il = 11.84%
		8120	48.17	18.86	16.35	1.30	0.46	8.00	6.87	Ch = 1.44%
		8680	58.36	15.40	11.97	1.78	0.79	6.72	4.98	Ca = 0.53%
		8730	53.43	15.83	12.02	1.76	1.71	9.60	5.66	Feld = 7.99%
		8830	72.31	10.56	6.82	1.02	0.77	5.81	2.70	Mon = 5.54%
		9150	58.62	18.53	11.31	1.99	0.00	5.77	3.78	

Note: Q = Quartz, K = Kaolinite, Il = Illite, Ch = Chorite, Ca = Calcite, Feld = Feldspar, Mon = Montmorillonite.

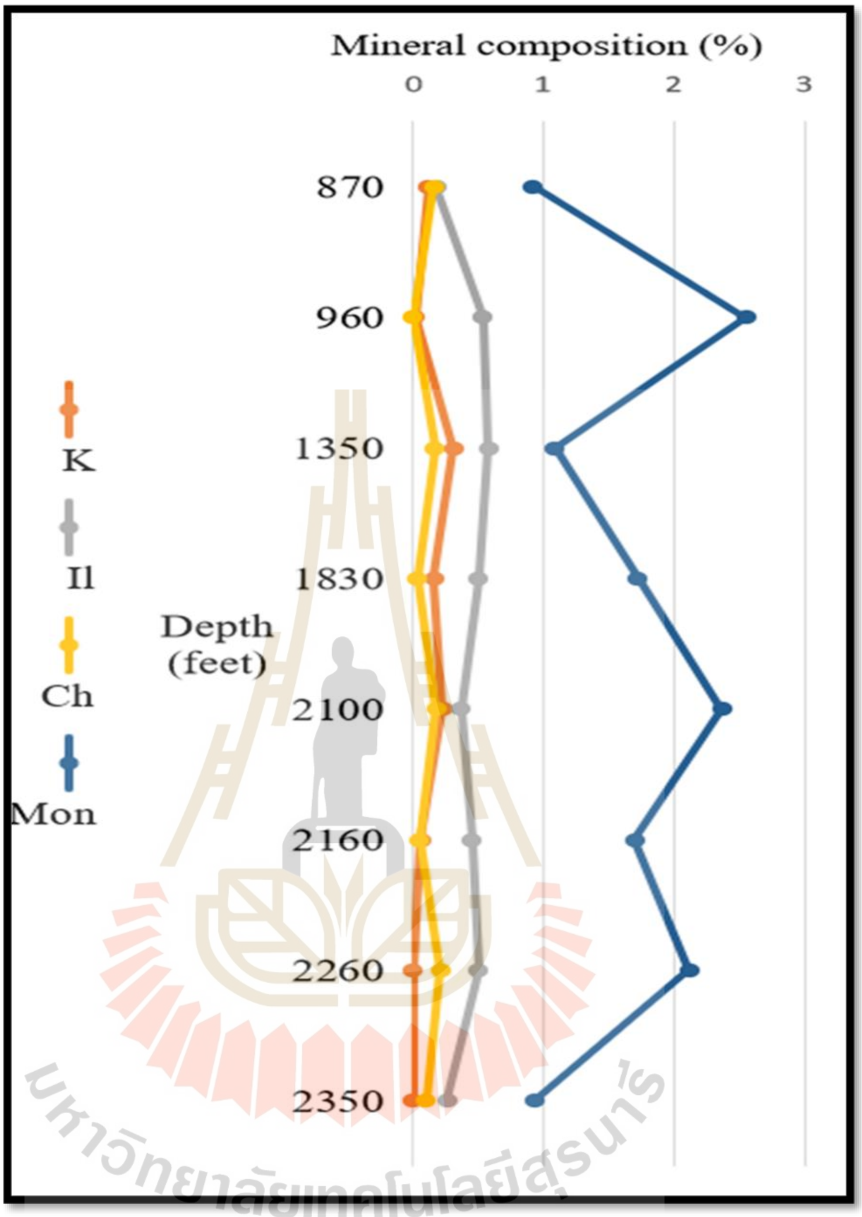


Figure 4.1 Mineral composition of Mae Fang Formation in FA-SS035-04 well.

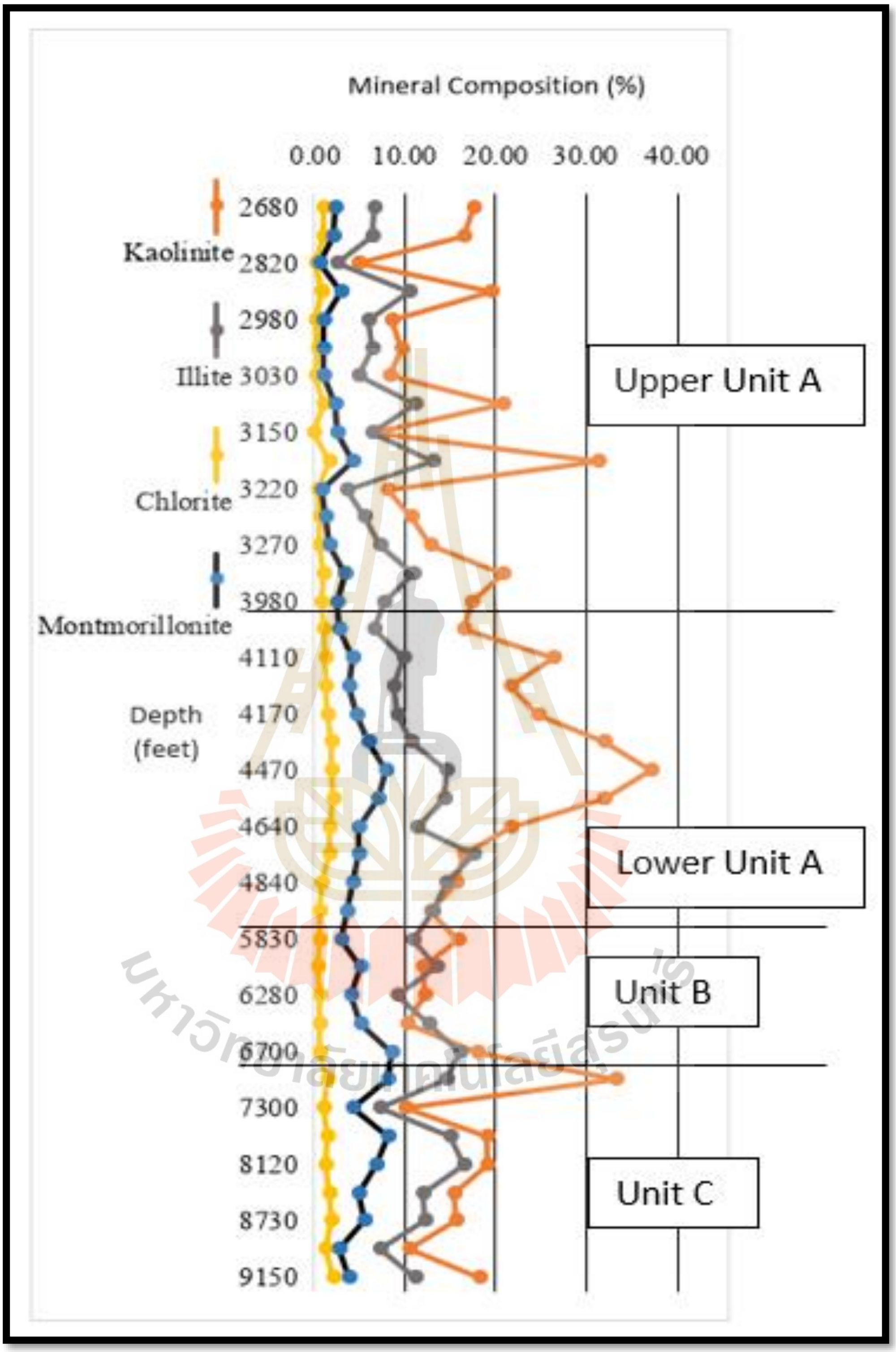


Figure 4.2 Mineral composition of Mae Sod Formation in FA-SS-35-04 well.

The Mae Fang Formation spans approximately 0 to 2,500 feet. As shown in Figures 4.1 and 4.3, the mineral composition percentages are as follows: quartz ranges from 84.5% to 94.05% (average 87.92%), kaolinite ranges from 0.00% to 0.31% (average 0.11%), illite ranges from 0.18% to 0.58% (average 0.42%), chlorite ranges from 0.00% to 0.21% (average 0.611%), calcite ranges from 0.03% to 0.14% (average 0.08%), feldspar ranges from 4.54% to 12.86% (average 9.69%), and montmorillonite ranges from 0.92% to 2.55% (average 1.68%). The montmorillonite content slightly increases with depth and reaches its highest value at 960 feet.

Figure 4.2 presents the mineral composition results of the Upper Unit A within the Mae Sod Formation, which spans approximately 2,500 to 3,980 feet. The percentage of mineral compositions is as follows: quartz ranges from 37.41% to 82.20% (average 63.99%), kaolinite ranges from 5.05% to 31.27% (average 14.52%), illite ranges from 1.75% to 13.05% (average 7.04%), chlorite ranges from 0.00% to 1.58% (average 0.63%), calcite ranges from 0.00% to 0.21% (average 0.02%), feldspar ranges from 7.62% to 17.49% (average 11.75%), and montmorillonite ranges from 0.59% to 4.16% (average 2.02%). The montmorillonite content slightly increases with depth and reaches its highest value at 3,180 feet.

The Lower Unit A of the Mae Sod Formation spans approximately 3,980 to 5,800 feet. The percentage of mineral compositions is as follows: quartz ranges from 28.38% to 62.11% (average 41.62%), kaolinite ranges from 12.94% to 37.65% (average 23.80%), illite ranges from 6.67% to 17.66% (average 11.53%), chlorite ranges from 0.48% to 1.92% (average 1.33%), calcite ranges from 0.00% to 33.09% (average 8.05%), feldspar ranges from 3.91% to 12.73% (average 9.04%), and montmorillonite ranges from 2.75% to 8.12% (average 9.04%). The montmorillonite content remains stable or slightly increases with depth and reaches high values at 4,360, 4,470, and 4,500 feet, respectively.

Unit B of the Mae Sod Formation spans approximately 5,800 to 6,800 feet. The percentage of mineral composition is as follows: quartz ranges from 7.97% to 41.03% (average 28.37%), kaolinite ranges from 10.18% to 17.84% (average 13.68%), illite ranges from 8.48% to 16.60% (average 12.31%).

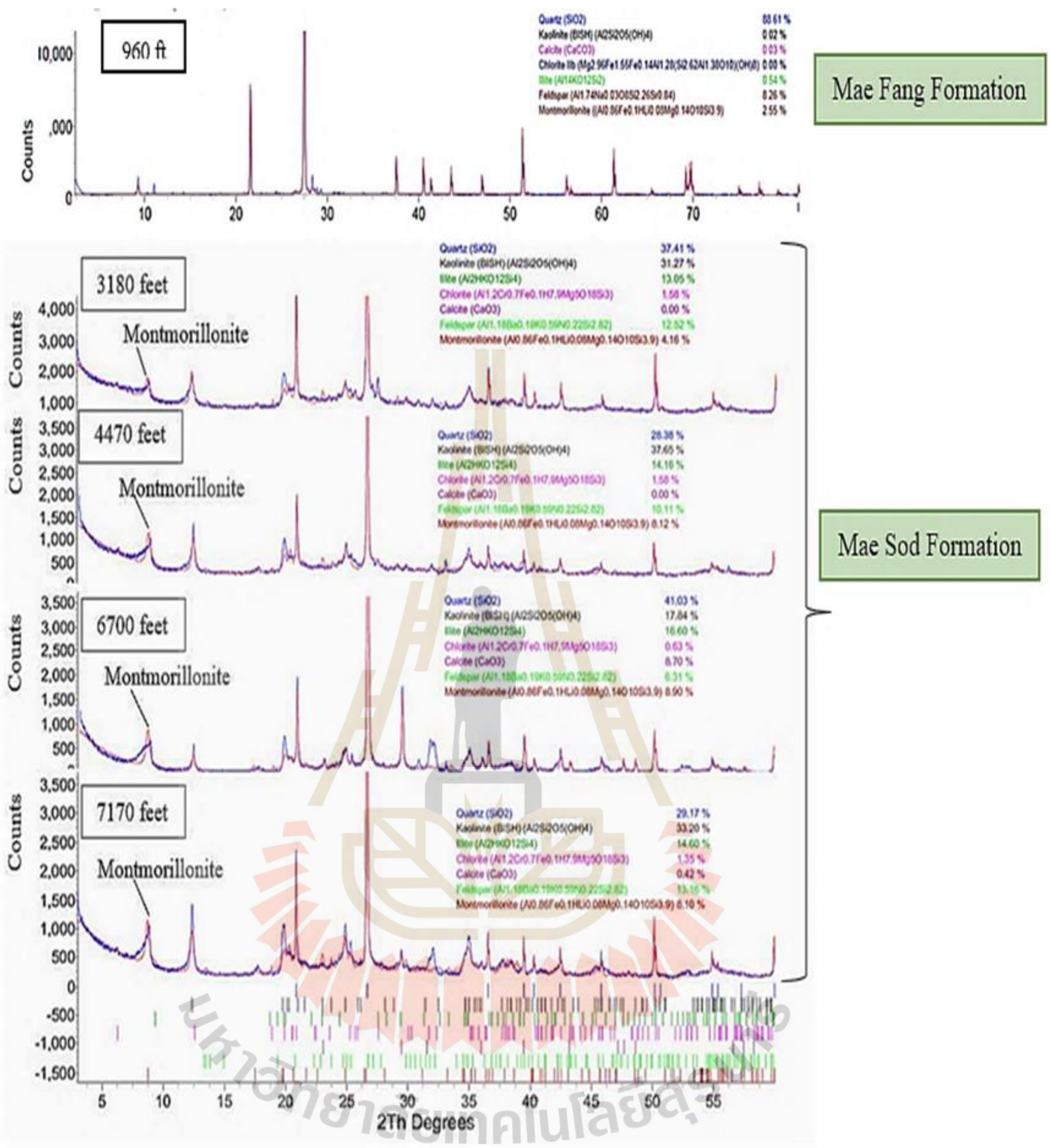


Figure 4.3 The XRD results from depths of 960, 3180, 4470, 6700, and 7170 ft.

4.2.2 Elemental Composition

The elemental composition as a result of the XRF analysis was shown in Table 4.2 and Figure 4.6. The study is focused on clay minerals, especially montmorillonite which causes shale swelling (Steinmetz, 2009). The result of elements of FA-SS-35-04 well of Fang Basin is given in Table 1 including Na_2O, MgO, Al_2O_3, Si_2O, K_2O, CaO, Cr_2O_3, MnO_2, Fe_2O_3, NiO, TiO_2, ZrO_2, and PbO. The Al_2O_3, Fe_2O_3, and MgO contents affect montmorillonite which relates to the shale swelling zone (Table 4.10 and Figure 4.4).

The results of the elemental composition analysis for the FA-SS-35-04 well in the Fang Basin deposit as presented in Table 4.2. The analyzed elements mainly Al_2O_3, Fe_2O_3, and MgO contents these compositions have an impact on montmorillonite, which is related to the shale swelling zone (Figure 4.6).

In the montmorillonite zone, the elemental composition shows a slight increase with depth. Specifically, the Al_2O_3 content ranges from 7.91% to 19.93% (average 12.47%), Fe_2O_3 ranges from 2.91% to 10.08% (average 4.79%), and MgO ranges from 1% to 2.44% (average 1.62%).

For Lower Unit A, the elemental composition in the montmorillonite zone also slightly increases with depth. The Al_2O_3 content ranges from 11.02% to 19.40% (average 14.74%), Fe_2O_3 ranges from 9.42% to 10.08% (average 4.79%), and MgO ranges from 2.18% to 3.33% (average 2.69%).

In Unit B, the elemental composition in the montmorillonite zone shows a slight increase with depth. The Al2O3 content ranges from 11.2% to 59.3% (average 13.46%), Fe2O3 ranges from 6.87% to 19.73% (average 12.38%), and MgO ranges from 2.21% to 2.98% (average 2.76%).

In Unit C, the elemental composition in the montmorillonite zone also slightly increases with depth. The Al_2O_3 content ranges from 11.38% to 23.03% (average 16.28%), Fe_2O_3 ranges from 5.09% to 8.77% (average 7.21%), and MgO ranges from 2.37% to 3.37% (average 2.96%). 2.37% to 3.37% (average 2.96%).

Table 4.10 Elemental compositions of Mae Sod Formation from FA-SS-35-04 well in San Sai Oil Filed.

Formation	Unit	Depth (ft.)	X-Ray Fluorescense (XRF) (%)												
			Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Cr_2O_3	MnO_2	Fe_2O_3	NiO	TiO_2	ZrO_2	PbO
Mae Sod	Upper of unit A	2680	4.956	2.379	14.534	64.272	1.802	0.948	0.069	0.350	10.079	0.004	0.594	0.007	0.019
		2790	3.360	1.074	11.056	77.677	2.487	0.427	0.083	0.078	3.402	0.000	0.344	0.003	0.011
		2820	3.865	1.116	10.668	77.907	2.265	0.364	0.074	0.053	3.328	0.001	0.319	0.001	0.010
		2950	3.469	0.998	8.741	79.461	2.296	0.281	0.086	0.067	3.098	0.000	0.211	0.001	0.009
		2980	4.913	1.962	16.706	68.096	2.635	0.308	0.079	0.097	4.566	0.006	0.613	0.003	0.019
		3000	3.112	1.030	7.910	82.244	1.341	0.734	0.145	0.073	3.213	0.000	0.240	0.000	0.007
		3030	4.519	2.436	19.928	64.485	1.930	0.441	0.048	0.076	5.165	0.007	0.935	0.011	0.018
		3080	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
		3150	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
		3180	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
		3220	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
		3240	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
		3270	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
		3930	4.952	2.144	15.184	65.155	1.829	0.354	0.051	0.471	9.111	0.005	0.707	0.005	0.019
		3980	5.040	2.396	14.522	66.494	1.981	0.336	0.037	0.505	7.985	0.004	0.675	0.008	0.017
	Lower of unit A	4020	5.102	2.201	13.231	64.628	1.839	0.290	0.259	0.745	11.221	0.005	0.636	0.008	0.022
		4110	4.703	2.571	16.780	62.457	2.119	0.317	0.042	0.641	9.416	0.007	0.910	0.007	0.030
		4140	4.912	2.555	14.458	62.963	1.818	0.295	0.060	0.598	11.513	0.005	0.784	0.006	0.032
		4170	3.145	2.506	14.978	62.130	1.922	0.339	0.055	0.530	13.237	0.010	0.882	0.009	0.036
		4360	4.348	2.860	16.286	53.852	1.874	0.636	0.340	0.932	18.155	0.015	0.958	0.006	0.043
		4470	4.158	3.008	19.403	54.669	2.388	0.630	0.039	0.401	13.934	0.019	1.300	0.011	0.042
		4500	4.077	3.325	17.867	52.038	2.364	3.529	0.037	0.462	14.984	0.017	1.250	0.008	0.041
		4640	4.528	2.831	13.699	55.589	1.803	6.477	0.039	0.475	13.507	0.010	1.012	0.003	0.026
		4740	7.800	2.950	12.558	46.004	1.535	11.192	0.034	0.909	16.170	0.010	0.843	0.000	0.027
		4840	7.257	2.594	11.857	51.381	1.631	11.257	0.039	0.642	12.320	0.011	0.986	0.002	0.024
		4940	6.203	2.180	11.017	46.536	1.572	18.894	0.335	0.502	12.059	0.013	0.959	0.005	0.013
	Unit B	5830	2.213	2.247	11.706	35.445	1.602	25.472	0.042	0.415	19.729	0.015	1.097	0.004	0.012
		6160	6.340	2.938	11.202	33.490	1.547	24.264	0.041	0.383	18.715	0.016	1.052	0.004	0.007
		6280	5.849	2.694	13.837	47.770	1.211	20.746	0.037	0.155	6.871	0.012	0.807	0.004	0.007
		6450	6.462	2.977	13.261	56.767	1.128	11.151	0.030	0.287	7.264	0.005	0.656	0.001	0.013
		6700	4.454	2.949	17.310	59.126	1.484	4.326	0.029	0.212	9.314	0.007	0.770	0.003	0.015
	Unit C	7110	4.025	2.854	23.031	57.489	2.317	0.986	0.169	0.155	7.813	0.012	1.249	0.010	0.015
		7300	4.968	2.370	12.199	72.659	1.379	0.356	0.075	0.194	5.091	0.003	0.690	0.009	0.008
		8110	4.451	3.366	18.205	60.900	2.163	0.837	0.062	0.133	8.512	0.015	1.337	0.013	0.005
		8120	4.534	3.218	17.562	61.372	2.060	0.969	0.054	0.136	8.766	0.018	1.298	0.014	0.006
		8680	4.826	2.939	15.539	64.522	1.737	1.145	0.052	0.170	8.050	0.011	0.986	0.017	0.006
		8730	4.618	3.288	16.414	61.854	1.852	1.673	0.047	0.253	6.178	0.011	1.125	0.014	0.007
		8830	4.956	2.737	11.383	71.500	1.174	1.068	0.062	0.138	6.274	0.006	0.683	0.008	0.007
		9150	4.844	2.941	15.888	65.583	1.541	1.026	0.073	0.116	7.024	0.008	0.930	0.013	0.011

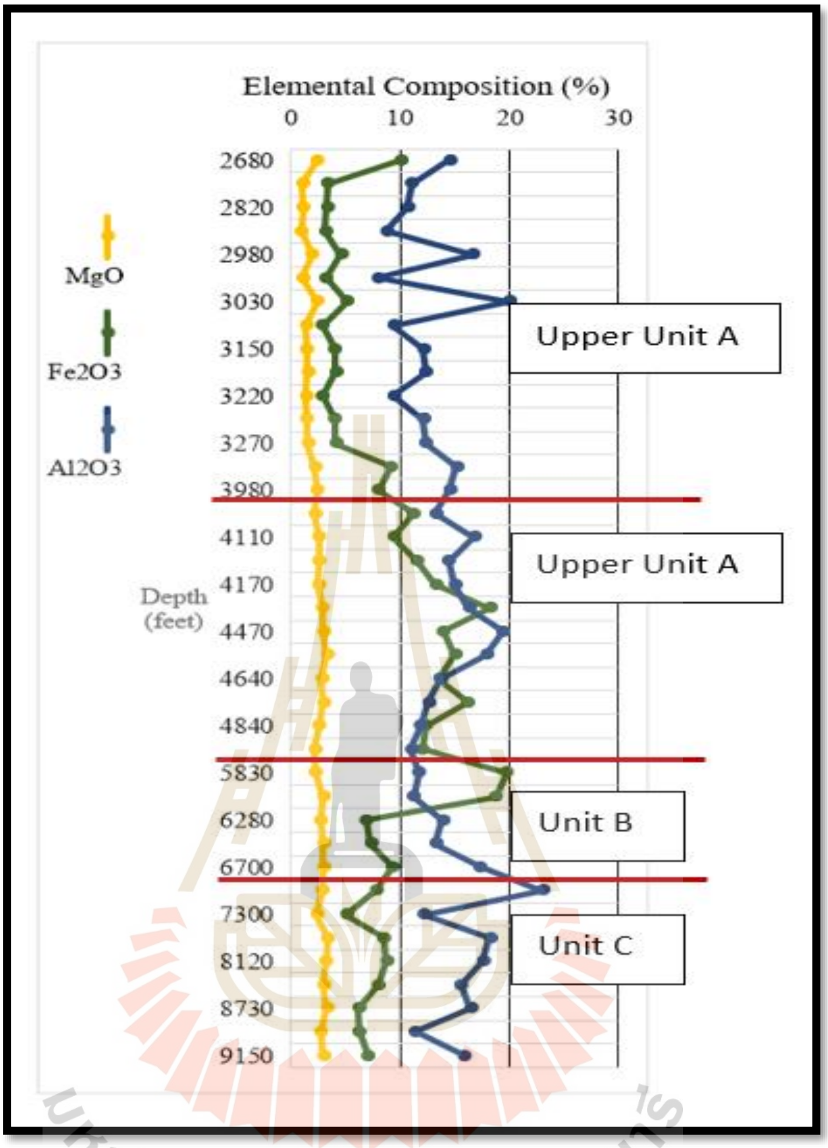


Figure 4.4 The elemental composition of Mae Sod Formation from FA-SS-35-04 well.

4.3 Well-logging Analysis

There are three parts to analyze data for identifying the shale swelling zone including a Gamma-ray log (GR) for shale volume calculation, a Density log measuring bulk density, and a Neutron log help for identifying porosity. All results of the Gamma-ray, Density, and Neutron log were shown in Table 4.11.

4.3.1 Gamma Ray Log (GR)

Based on the calculation using Equation (3.1), the shale volume of all samples varies from 0.42% to 8.75% for depths ranging from 2,820 to 9,150 feet. This information is presented in Table 4.11 and Figure 4.5.

For Upper Unit A, the shale volume ranges from 16.80% to 80.28%, with the highest shale volume values observed at depths of 3,150 and 3,180 feet.

In Lower Unit A, the shale volume ranges from 17.5% to 87.5%, and the highest shale volume values are found at depths of 4,020, 4,140, 4,170, and 4,360 feet.

Unit B exhibits shale volume between 2.08% and 50.0%, with the highest shale volume value occurring at a depth of 6,700 feet.

Unit C, the shale volume ranges from 0.42% to 6.67%, and the highest shale volume value is observed at a depth of 7,110 feet.

From the Gamma-ray log data, it was found that the shale volume in the Mae Sod Formation interbedded sandstone and shale. The shale volume increases significantly in Upper Unit A and decreases in Lower Unit A. Additionally, there is a substantial increase in shale volume within Unit B and Unit C.

Table 4.11 Result of Gamma-ray, Density, and Neutron log data.

Formation	Unit	Depth (ft.)	Gamma Ray log		Density log	Neutron log	Average
			API	Shale volume(%)	Density (g/cc)	PU (%)	
Mae Sod	Upper of unit A	2680	-	-	-	-	
		2790	-	-	-	-	
		2820	-	-	-	-	
		2950	212	0.516	2.15	5.00	
		2980	240	0.628	2.13	7.10	Shalve volume =56.3%
		3000	180	0.388	2.15	25.00	Density = 2.1 %
		3030	230	0.588	2.04	7.00	Neutron Porosity = 3.8-25%
		3080	125	0.168	2.16	20.00	
		3150	290	0.828	1.95	3.80	
		3180	275	0.768	2.17	5.00	
		3220	240	0.628	1.97	6.30	
		3240	245	0.648	2.00	4.10	
		3270	205	0.488	1.93	5.00	
		3930	238	0.620	2.35	5.00	
		3980	205	0.488	2.16	5.00	
	Lower of unit A	4020	220	0.725	2.00	8.80	
		4110	200	0.625	2.35	8.00	
		4140	220	0.725	2.27	6.80	
		4170	220	0.725	2.25	4.50	Shalve volume =55%
		4360	250	0.875	2.31	7.00	Density = 2.27 %
		4470	200	0.625	2.05	8.00	Neutron Porosity = 4.5-20%
		4500	185	0.550	2.2	6.80	
		4640	160	0.425	2.32	15.00	
		4740	140	0.325	2.45	17.00	
		4840	130	0.275	2.33	20.00	
		4940	110	0.175	2.43	10.00	
	Unit B	5830	120	0.222	-	-	
		6160	115	0.208	-	-	Shalve volume =28.6%
		6280	125	0.236	-	-	
		6450	135	0.264	-	-	
		6700	220	0.500	-	-	
	Unit C	7110	280	0.667	-	-	
		7300	150	0.306	-	-	
		8110	55	0.042	-	-	
		8120	140	0.278	-	-	Shalve volume =24.8%
		8680	70	0.083	-	-	
		8730	100	0.167	-	-	
		8830	110	0.194	-	-	
		9150	-	-	-	-	

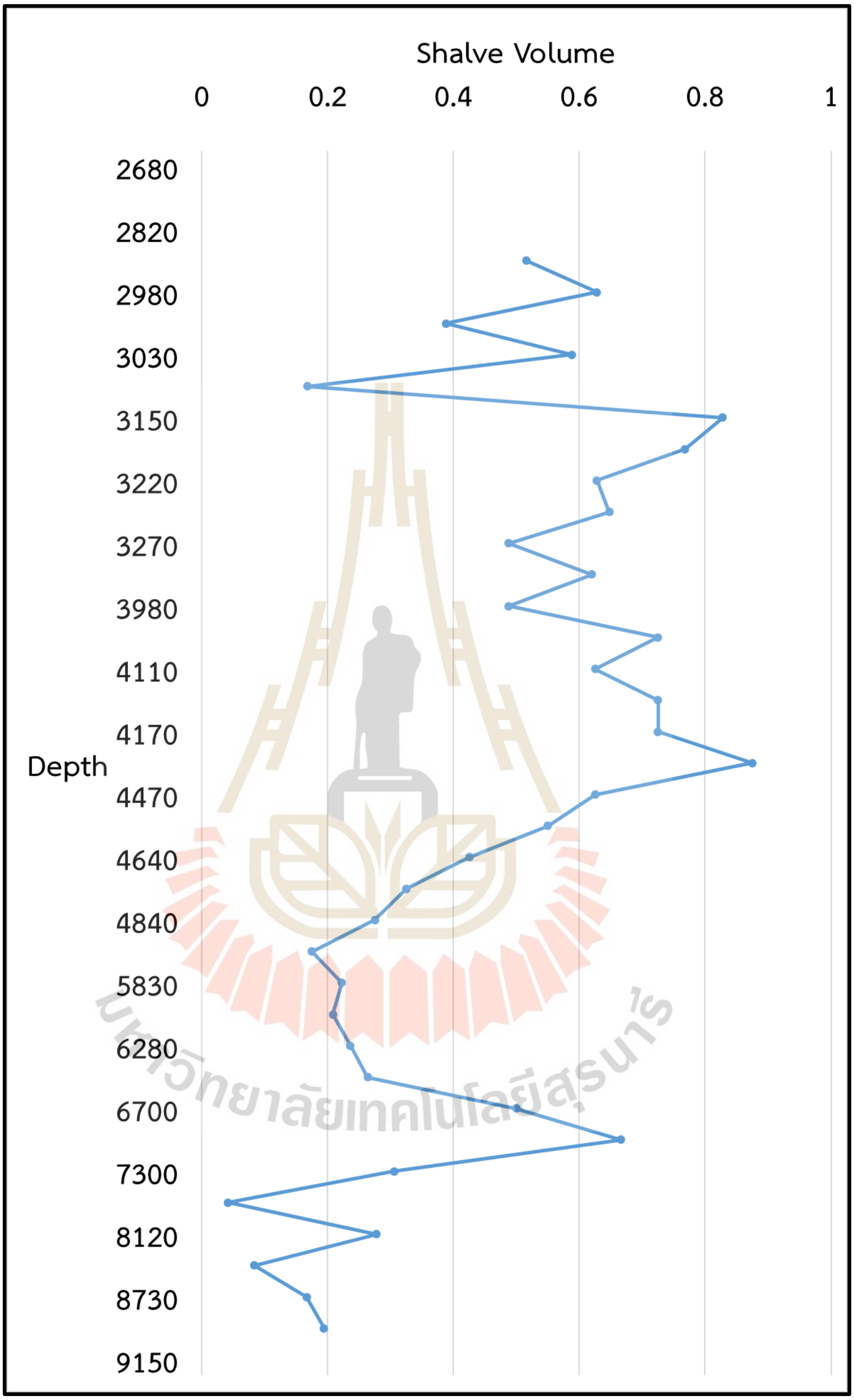


Figure 4.5 The shale volume of Mae Sod Formation (FA-SS-35-04 well) from Gamma Ray log.

4.3.2 Density Log

The density log measures the bulk density in the unit gram per cubic centimeters (g/cc) as the results from Table 4.11 and Figure 4.6. The density slightly increased with depth for upper unit A has 1.93 to 2.35 g/cc. (avg 2.10 g/cc) and lower unit A has 2.00 – 2.45 g/cc (aver = 2.27 g/cc). The density relates to shale density (2.06 -2.67 g/cc).

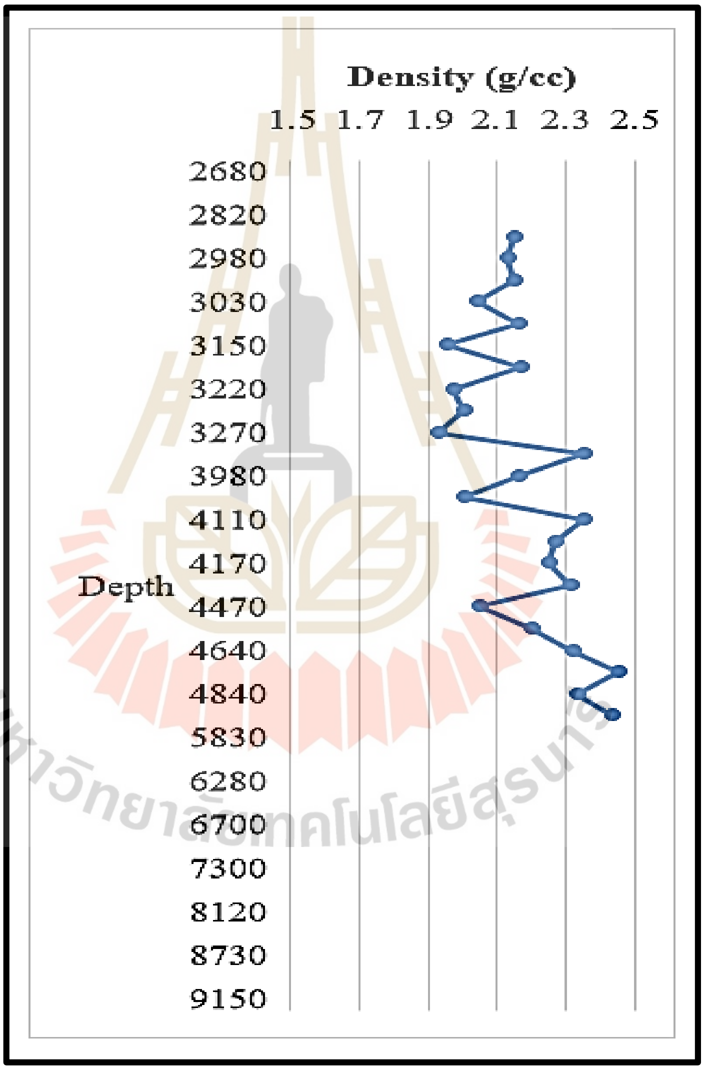


Figure 4.6 Density data from FA-SS-35-04 well from Density log.

4.3.3 Neutron Log

The neutron log is used to detect the number of hydrogen atoms in Formation and refer to the porosity of the Formation. From Figure 4.7 the Upper unit A of the Mae Sod Formation has 3.8-25%) and the Lower unit A of the Mae Sod Formation has 4.5-20%. From the porosity data, it was found that the porosity of the shale was about 4-8% and that the porosity was high in the intervening rocks of the sandstone (Sandy Shale). Unit A (Mae Sod Formation) has the accumulation of petroleum and the accumulation of sandstone interbedded with shale according to the lacustrine or lake (fresh) deposition environment.

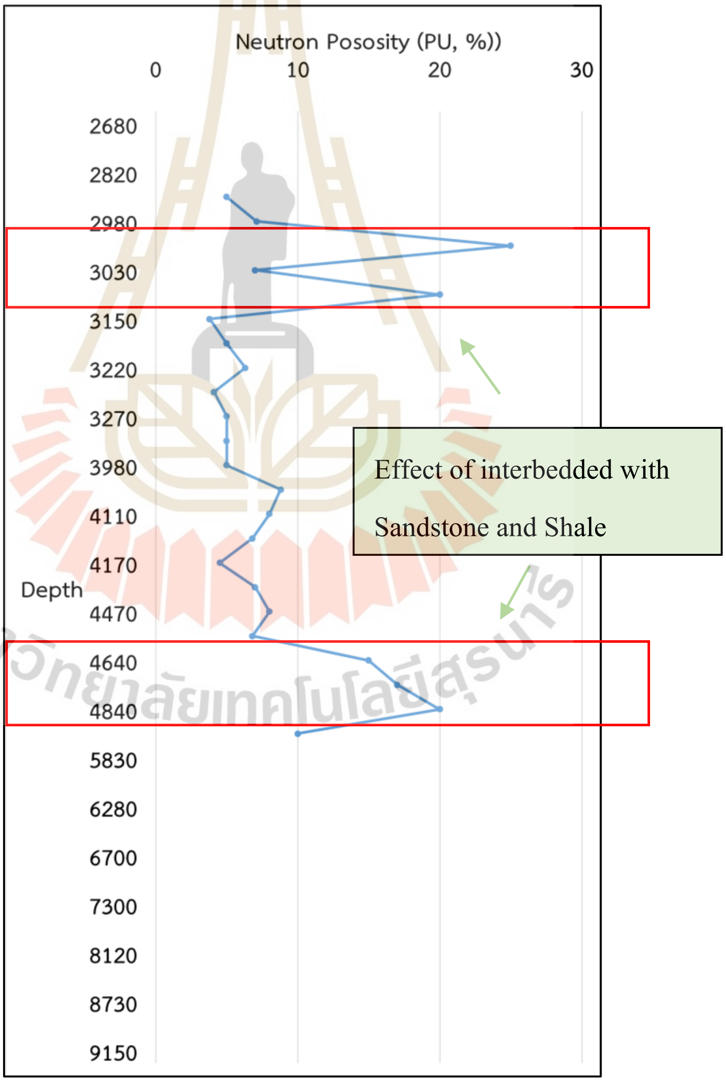


Figure 4.7 The volume from the neutron log of FA-SS-35-04 well from the Neutron log.

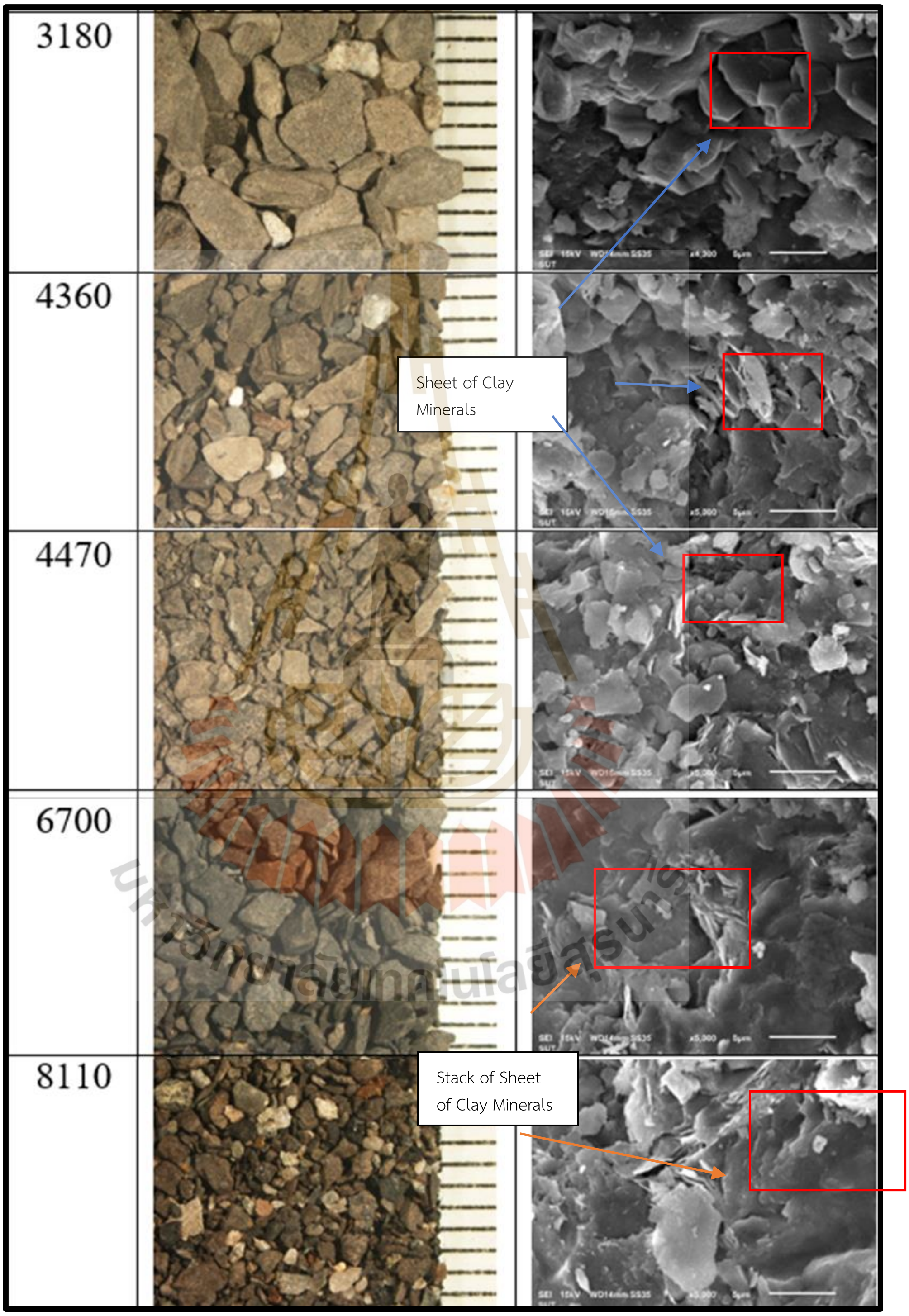
4.4 Correlation of Chemical and Physical Properties

Mae Fang Formation (0 – 2500 feet) is composed of mainly sand size and high quartz and cutting is not shown the characteristic of clay minerals. The Mae Sod Formation (2500 – 9200 feet), the cutting shown sheet of clay minerals or feasibility due to fracture under nature of shale. Moreover, the cutting also represents a round shape, light gray to reddish brown clay which originates from the fluvial deposit (Table 4.12). The chemical properties are consistent with the XRD and XRF the content of montmorillonite is increased with depth, and relative to the content of MgO, Fe2O3, and Al2O3. Highly montmorillonite is selected for a scanning electron microscope test that shows a stack of sheet clay minerals.

Figure 4.8 showed the ranges of shale volume in Mae Sod Formation are 17 to 88% based on the estimated GR log and shows a trend of shale volume increasing with depth at Upper Unit A and then the shale volume decreasing with depth at Lower Unit A, Unit B and show the lowest shale volume at Unit C. Thes result of chemical analysis from thirty-nine drill cuttings of Mae Sod Formation from FA-SS-35-04 well represented 4 types of clay minerals including 5.05 to 37.65% of kaolinite, 1.75 to 17.66% of illite, 0 to 1.99% of chlorite, and 0.59 to 8.9% of montmorillonite. As according of montmorillonite impacts significantly shale swelling, which is represented in all units of Mae Sod Formation increasing with depth and the trend of mineral association of montmorillonite increased with depth (Al2O3, Fe2O3, and MgO.). The trend of montmorillonite content slightly increases with depth according to the Upper- and Lower-Unit A, Unit B, and Unit C, respectively. As the montmorillonite content is more than 4.92%.

The lithology of the rock layers varies depending on the different depositional environments, leading to varying quantities of clay minerals in the sediment. The data from the Gamma-ray log shows the interbedding of sandstone and shale, with varying amounts of Montmorillonite clay mineral present. Montmorillonite content increases significantly in the Lower Unit A, Unit B, and Unit C related with the increasing trend of oxidized elemental components, namely Na2O, MgO, Al2O3, and CaO, as the depth increases.

Table 4.12 The result of the Scanning Electron Microscope (SEM) show flak sheet of clay mineral at 3180, 460, 4470, 6700, and 8110 ft.



4.5 Correlation of Well Logging Data and Clay Minerals

From the study of the clay mineral composition of the FA-SS-35-04 well, it was found that it consists of four types of clay minerals: Kaolinite, Illite, chlorite, and montmorillonite. The quantities of these clay minerals vary with depth and environment deposit can be correlated with the data from the well's Gamma-ray log as follows in Table 4.13. and 4.14. The summary of data in Table 4.15.-4.18

Correlation well log and clay minerals specifically focusing on the Montmorillonite mineral content, it was found that in the upper Unit A, where the Montmorillonite content is high at depths from 3080 to 3220 feet, the natural Gamma-ray readings ranged from 125 to 240 API. The density values in this depth interval were between 1.95 to 2.17 g/cc, and the Neutron log values ranged from 0.66 to 0.78.

Lower Unit A showed the high content of montmorillonite at depths 4170 to 4470 feet and response to the Gamma-ray log ranged 140 to 250 API. Density has shown of a bulk volume of 2.05 -2.45 g/cc and the Neutron Porosity log has shown a range of 3.8-8%.

Unit B showed the high Montmorillonite content at 6160 to 6700 feet with 3.99 to 8.56% of Montmorillonite content and respond to Gamma-ray log 115 – 220 API.

Unit C is the lowest of lithology showing 4.2 to 8.1 % of Montmorillonite content at 7110 to 8730 feet and responding to Gamma ray log 55 to 280 API.

Table 4.13 Log response to clay minerals correlation.

NO.	Unit	Depth (ft.)	Gamma Ray log		Density log	Neutron log	X-Ray Diffraction (XRD) (%)							X-Ray Fluorescense (XRF) (%)												
			API	hale volume(%	Density (g/cc)	Porosity (%)	Quartz	Kaolinite	Illite	Chlorite	Calcite	Felspar	ntmorillo	Na2O	MgO	Al2O3	SiO2	K2O	CaO	Cr2O3	MnO2	Fe2O3	NiO	TiO2	ZrO2	PbO
1	Upper of unit A	2680	-	-	-	-	63.265	17.525	6.655	0.960	0.000	9.030	2.385	4.956	2.379	14.534	64.272	1.802	0.948	0.069	0.350	10.079	0.004	0.594	0.007	0.019
2		2790	-	-	-	-	65.845	16.455	6.335	0.915	0.000	8.415	2.040	3.360	1.074	11.056	77.677	2.487	0.427	0.083	0.078	3.402	0.000	0.344	0.003	0.011
3		2820	-	-	-	-	82.510	4.795	2.485	0.225	0.010	9.480	0.515	3.865	1.116	10.668	77.907	2.265	0.364	0.074	0.053	3.328	0.001	0.319	0.001	0.010
4		2950	212	0.516	2.15	5.00	53.940	19.570	10.380	0.780	0.000	12.300	3.030	3.469	0.998	8.741	79.461	2.296	0.281	0.086	0.067	3.098	0.000	0.211	0.001	0.009
5		2980	240	0.628	2.13	7.10	68.420	8.510	5.870	0.170	0.000	16.030	1.000	4.913	1.962	16.706	68.096	2.635	0.308	0.079	0.097	4.566	0.006	0.613	0.003	0.019
6		3000	180	0.388	2.15	25.00	68.740	9.610	6.400	0.360	0.000	13.910	0.980	3.112	1.030	7.910	82.244	1.341	0.734	0.145	0.073	3.213	0.000	0.240	0.000	0.007
7		3030	230	0.588	2.04	7.00	70.760	8.320	4.770	0.230	0.000	14.960	0.960	4.519	2.436	19.928	64.485	1.930	0.441	0.048	0.076	5.165	0.007	0.935	0.011	0.018
8		3080	125	0.168	2.16	20.00	47.380	20.760	11.080	0.930	0.000	17.490	2.360	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
9		3150	290	0.828	1.95	3.80	75.220	6.530	6.260	0.000	0.000	9.480	2.510	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
10		3180	275	0.768	2.17	5.00	37.410	31.270	13.050	1.580	0.000	12.520	4.160	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
11		3220	240	0.628	1.97	6.30	77.440	8.190	3.560	0.300	0.210	9.450	0.850	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
12		3240	245	0.648	2.00	4.10	68.480	10.680	5.540	0.550	0.050	13.500	1.200	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
13		3270	205	0.488	1.93	5.00	64.540	12.760	7.260	0.490	0.020	13.310	1.620	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
14		3930	238	0.620	2.35	5.00	54.075	20.755	10.810	1.075	0.000	10.040	3.255	4.952	2.144	15.184	65.155	1.829	0.354	0.051	0.471	9.111	0.005	0.707	0.005	0.019
15		3980	205	0.488	2.16	5.00	60.375	17.265	7.550	0.750	0.000	11.600	2.440	5.040	2.396	14.522	66.494	1.981	0.336	0.037	0.505	7.985	0.004	0.675	0.008	0.017
16	Lower of unit A	4020	220	0.725	2.00	8.80	62.110	16.460	6.665	0.985	0.000	11.025	2.750	5.102	2.201	13.231	64.628	1.839	0.290	0.259	0.745	11.221	0.005	0.636	0.008	0.022
17		4110	200	0.625	2.35	8.00	47.310	26.420	9.830	1.215	0.000	11.105	4.115	4.703	2.571	16.780	62.457	2.119	0.317	0.042	0.641	9.416	0.007	0.910	0.007	0.030
18		4140	220	0.725	2.27	6.80	55.485	21.665	8.705	1.220	0.000	9.170	3.745	4.912	2.555	14.458	62.963	1.818	0.295	0.060	0.598	11.513	0.005	0.784	0.006	0.032
19		4170	220	0.725	2.25	4.50	51.600	24.640	9.235	1.340	0.000	8.570	4.610	3.145	2.506	14.978	62.130	1.922	0.339	0.055	0.530	13.237	0.010	0.882	0.009	0.036
20		4360	250	0.875	2.31	7.00	41.405	32.005	10.665	1.955	0.000	8.125	5.835	4.348	2.860	16.286	53.852	1.874	0.636	0.340	0.932	18.155	0.015	0.958	0.006	0.043
21		4470	200	0.625	2.05	8.00	28.380	37.050	14.500	1.895	0.000	10.270	7.905	4.158	3.008	19.403	54.669	2.388	0.630	0.039	0.401	13.934	0.019	1.300	0.011	0.042
22		4500	185	0.550	2.2	6.80	28.970	32.000	14.360	2.105	5.075	10.395	7.095	4.077	3.325	17.867	52.038	2.364	3.529	0.037	0.462	14.984	0.017	1.250	0.008	0.041
23		4640	160	0.425	2.32	15.00	43.420	21.685	11.370	1.585	10.670	6.450	4.830	4.528	2.831	13.699	55.589	1.803	6.477	0.039	0.475	13.507	0.010	1.012	0.003	0.026
24		4740	140	0.325	2.45	17.00	35.495	16.550	17.580	1.645	19.395	4.560	4.765	7.800	2.950	12.558	46.004	1.535	11.192	0.034	0.909	16.170	0.010	0.843	0.000	0.027
25		4840	130	0.275	2.33	20.00	39.605	15.558	14.578	0.700	19.825	5.050	4.220	7.257	2.594	11.857	51.381	1.631	11.257	0.039	0.642	12.320	0.011	0.986	0.002	0.024
26		4940	110	0.175	2.43	10.00	33.080	12.705	12.940	0.550	33.110	4.050	3.565	6.203	2.180	11.017	46.536	1.572	18.894	0.335	0.502	12.059	0.013	0.959	0.005	0.013
27	Unit B	5830	120	0.222	-	-	20.215	15.725	10.965	0.525	45.290	4.300	2.970	2.213	2.247	11.706	35.445	1.602	25.472	0.042	0.415	19.729	0.015	1.097	0.004	0.012
28		6160	115	0.208	-	-	17.825	11.940	13.370	0.410	45.820	5.485	5.155	6.340	2.938	11.202	33.490	1.547	24.264	0.041	0.383	18.715	0.016	1.052	0.004	0.007
29		6280	125	0.236	-	-	22.975	12.190	9.115	0.575	46.450	4.715	3.985	5.849	2.694	13.837	47.770	1.211	20.746	0.037	0.155	6.871	0.012	0.807	0.004	0.007
30		6450	135	0.264		-	39.950	10.130	12.690	0.480	27.225	4.500	5.025	6.462	2.977	13.261	56.767	1.128	11.151	0.030	0.287	7.264	0.005	0.656	0.001	0.013
31		6700	220	0.500	-	-	40.650	17.885	15.950	0.505	8.835	7.610	8.560	4.454	2.949	17.310	59.126	1.484	4.326	0.029	0.212	9.314	0.007	0.770	0.003	0.015
32	Unit C	7110	280	0.667	-	-	29.170	33.200	14.600	1.350	0.420	13.160	8.100	4.025	2.854	23.031	57.489	2.317	0.986	0.169	0.155	7.813	0.012	1.249	0.010	0.015
33		7300	150	0.306	-	-	72.590	10.120	7.135	0.985	0.000	4.980	4.195	4.968	2.370	12.199	72.659	1.379	0.356	0.075	0.194	5.091	0.003	0.690	0.009	0.008
34		8110	55	0.042	-	-	46.970	19.010	14.905	1.360	0.140	9.635	7.980	4.451	3.366	18.205	60.900	2.163	0.837	0.062	0.133	8.512	0.015	1.337	0.013	0.005
35		8120	140	0.278	-	-	47.750	19.145	16.370	1.135	0.485	8.265	6.850	4.534	3.218	17.562	61.372	2.060	0.969	0.054	0.136	8.766	0.018	1.298	0.014	0.006
36		8680	70	0.083	-	-	57.500	15.400	11.875	1.650	0.925	7.695	4.955	4.826	2.939	15.539	64.522	1.737	1.145	0.052	0.170	8.050	0.011	0.986	0.017	0.006
37		8730	100	0.167	-	-	54.500	15.505	12.255	1.960	1.515	8.670	5.605	4.618	3.288	16.414	61.854	1.852	1.673	0.047	0.253	6.178	0.011	1.125	0.014	0.007
38		8830	110	0.194	-	-	72.755	10.555	7.150	1.135	0.635	5.085	2.675	4.956	2.737	11.383	71.500	1.174	1.068	0.062	0.138	6.274	0.006	0.683	0.008	0.007
39		9150	-	-	-	-	58.030	18.135	11.190	2.005	0.130	6.740	3.770	4.844	2.941	15.888	65.583	1.541	1.026	0.073	0.116	7.024	0.008	0.930	0.013	0.011

Table 4.14 Relation of Log data, X-ray Diffraction data, and X-ray Fluorescence in Mae Sod Formation of FA-SS-35-04 well

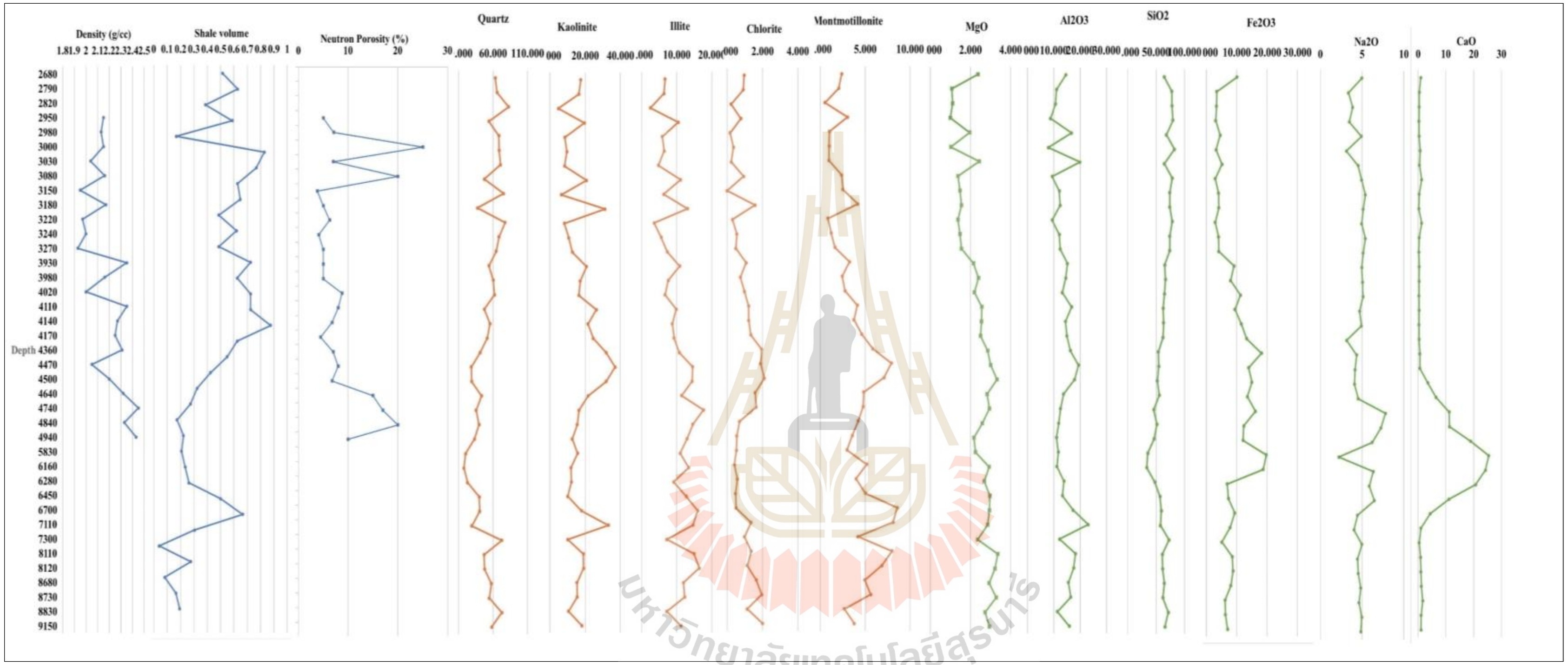


Table 4.15 Summary of Mae Fang Formation of FA-SS-35-04 well analysis.

Fm.	Depth (ft.)	Cuttings	Lithology	Logging	Chemical analysis
Mae Fang	120 -2500		▪ 8 Samples ▪ Depth: ~2500 feet ▪ Formation: Mae Fang ▪ Age: Pleistocene – Recent (2.58 Ma- Recent ▪ Lithology: Mainly of Gravel ▪ Color: Light gray to gray ▪ Environment Deposition: Fluvial deposit		Q = 87.9% K = 0.11% Ill = 0.42% Ch = 0.11% Ca= 0.08% Feld= 9.69% Mon= 1.58%

Table 4.16 Summary of Unit A (Mae Sod Formation) of FA-SS-35-04 well analysis.

Fm.		Depth (ft.)	Cuttings	Lithology	Logging	Chemical analysis
Mae Sod	Upper Unit A	2500-3980		▪ 26 samples ▪ Depth: 2,500 to 5,800 feet ▪ Formation: Mae Sod ▪ Age: Early Miocene – Late Pliocene ▪ (23Ma – 2.58Ma) ▪ Color: gray to dark gray and brown color ▪ Lithology: Sand, Shale ▪ Environment Deposition: lacustrine ▪ Petroleum system: Reservoir, Seal trap	▪ Shale volume =56.3% ▪ Density = 2.1 % ▪ Neutron Porosity = 3.8-25%	Q = 63.99% K = 14.52% Ill = 7.04% Ch = 0.53% Ca= 0.02% Feld= 11.75% Mon= 2.02%
Mae Sod	Lower Unit A	3980-5800			▪ shale volume =55% ▪ Density = 2.27 % Neutron Porosity = 4.5-20%	Q = 41.62% K 23.80% Ill = 11.53% Ch = 1.33% Ca= 8.05% Feld= 9.04% Mon= 4.96%

Table 4.17 Summary of Unit B (Mae Sod Formation) of FA-SS-35-04 well analysis.

Fm.		Depth (ft.)	Cuttings	Lithology	Logging	Chemical analysis
Mae Sod	Unit B	5800-6800		▪ 5 samples ▪ Depth: 5,800 to 6,800 feet ▪ Formation: Mae Sod ▪ Age: Oligocene (33.9Ma – 23Ma) ▪ Color: gray to dark ▪ Lithology: thick dark-gray shale, fine-grained sandstone ▪ Environment Deposition: low-energy conditions of freshwater paleo-lake ▪ Petroleum system: Source rock	shale volume =28.6%	Q = 28.37% K = 13.68% Ill = 12.31% Ch = 0.56% Ca= 8.05% Feld= 5.12% Mon= 5.3%

Table 4.18 Summary of Unit C (Mae Sod Formation) of FA-SS-35-04 well analysis.

Fm.		Depth (ft.)	Cuttings	Lithology	Logging	Chemical analysis
Mae Sod	Unit C	6800-9200		▪ 8 samples ▪ Depth: 6,800 to 9,200 feet ▪ Formation: Mae Sod ▪ Age: Late Eocene or Older o (56Ma – 33.9Ma or Older) ▪ Color: generally red and gray ▪ Lithology: part of sandstone and a coal bed interbedded with black shale ▪ Environment Deposition: marginal lacustrine	shale volume =24.8%	Q = 28.37% K = 13.68% Ill = 12.31% Ch = 0.56% Ca= 8.05% Feld= 5.12% Mon= 5.3%

4.6 Swelling Shale Zone Interpretation

According to the mineral and elemental contents in Mae Sod Formation from the FA-SS-35-04 well, it has depths ranging from 2,600 feet to 9,200 feet. The mineral compositions are 17.97 to 82.20% quartz (avg. 51.26%), 5.05 to 37.65% kaolinite (avg. 17.68%), 1.75 to 17.66% illite (avg. 9.97%), 0.99% chlorite (avg. 0.99%), 0 to 46.57% calcite (avg. 6.83%), 3.91 to 17.49% of feldspar (avg. 9.27%), and 0.59 to 8.90% of montmorillonite (avg. 3.99%). The mineral compositions are 17.97 to 82.20% quartz (avg. 51.26%), 5.05 to 37.65% of kaolinite (avg. 17.68%,), 1.75 to 17.66% of illite (avg. 9.97%), 0 to 1.99% of chlorite (avg. 0.99%), 0 to 46.57% of calcite (avg. 6.83%), 3.91 to 17.49% of feldspar (avg. 9.27%), and 0.59 to 8.90% of montmorillonite (avg. 3.99%). The elemental compositions contain 7.91 to 23.03% (avg. 4.02%) of Al2O3, 2.91 to 19.73% (avg. 8.67%) of Fe2O3, and 1.0 to 3.37% (avg. 2.35%) of MgO. 2.21 to 7.80% (avg. 4.82%) of Na2O3, 0.23 to 25.47% (avg. 4.82%) of CaO. As the data shows, FA-SS-35-04 well cuttings mostly consist of kaolinite, illite, montmorillonite, and chlorite as clay minerals. These clay mineral compositions increase with depth, especially the montmorillonite affected by the shale swelling zone. Moreover, the average montmorillonite content represents 2.02 % of Upper Unit A, 4.96% of Lower Unit A, 5.30% of Unit B, and 5.54% of Unit C.

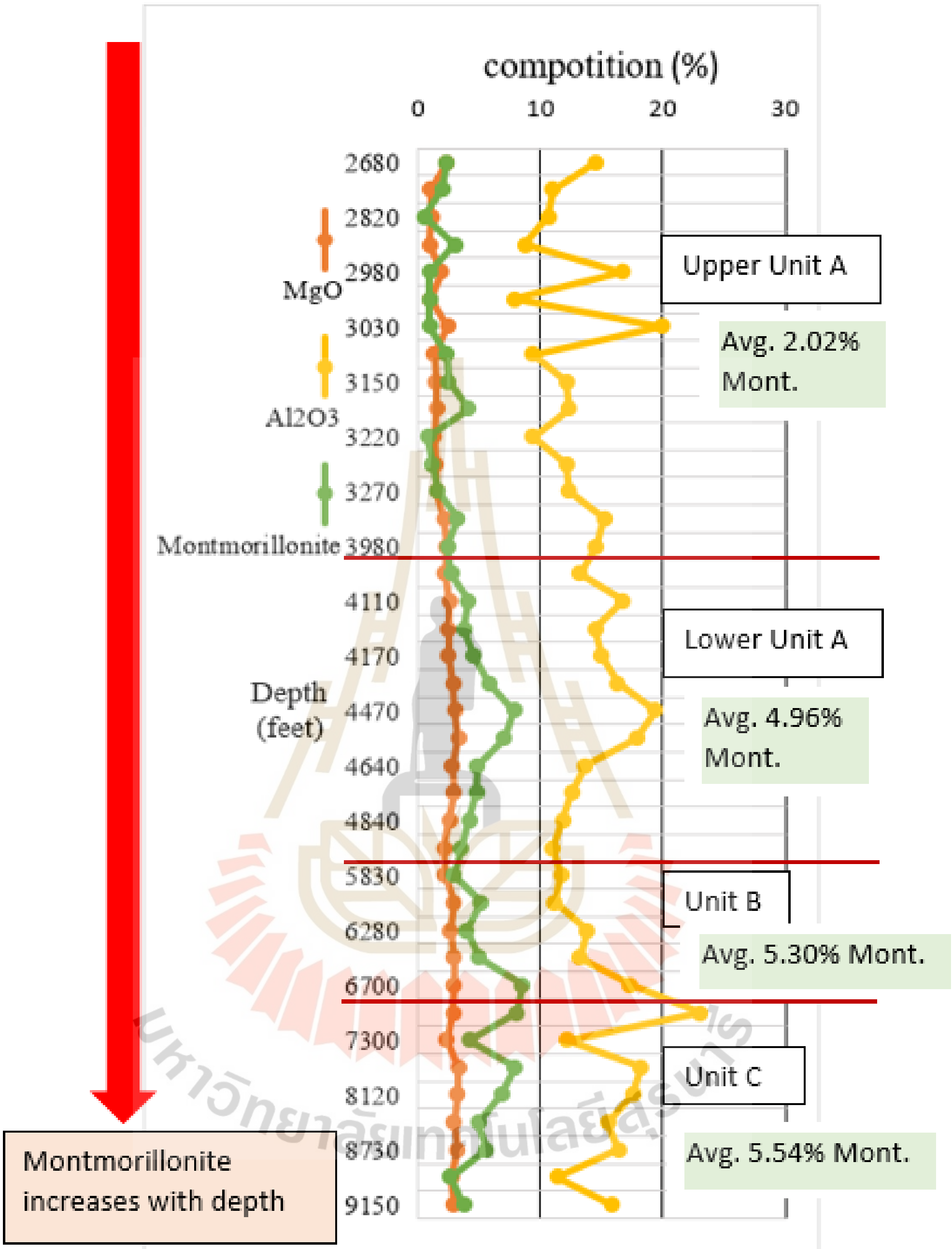


Figure 4.8 The trending of montmorillonite content in Mae Sod Formation.

In Figure 4.8, montmorillonite content increases with depth for Unit A, Unit B, and Unit C, respectively. The montmorillonite content is greater than 4.92% (Phiriya-anuphon, 2017). This could be the result of swelling in the lower zone of the Mae Sod Formation (Units C and B) may be aware of shale swelling during drilling. These results can be used for planning drilling through this formation for the future drilling well in the Fang Basin.

Shale zone. Consequently, the shale layer of Unit C (at 7,170, 8,180, 8,120, 8,680-, and 8,730-feet depth) is more swollen than Unit B (at 6,160, 6,450, and 6,700 ft. depth), Lower Unit A (at 3,180 ft. depth). As a result of this study,

Swelling in shale is a chemical reaction that is influenced by time and factors for exchange ionization. In drilling, lithology data records are crucial because they may not be visible on day one, but after several days (DrillingFormulas.Com, 2011). Mineral composition, elemental composition, and logging data may help plan, avoid, and protect drilling operations.

Exploration and development require drilling mud to maintain pressure and cooling, as well as to bring cuttings to the surface while protecting the formation layer, filtering, and exchanging ions. Data about the well or basin can be used to optimize drilling fluid by choosing oil-based mud or additive materials appropriately.

Several methods can be used to reduce clay swelling, such as adding sylvile (KCl) and polymer to water-based drilling mud. Furthermore, oil-based drilling muds can be used in this swelling zone as shown in Figure 4.9 based on the study of the efficiency of reducing swelling shale in the Fang Oil field (Nakawong, 2017).

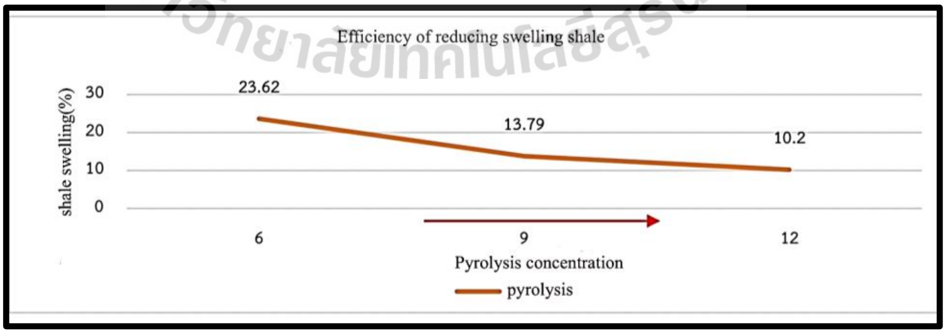


Figure 4.9 Efficiency of reducing swelling shale of pyrolysis oil (Nakawong, 2017)

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CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Clay mineral and elemental composition of FA-SS-35-04 well

In Mae Fang Formation, sediments are primarily coarse clastic sediments that reach a depth of about 2,500 feet. According to the analysis of 8 samples, the following minerals were found: quartz (87.92%), kaolinite (0.11%), chlorite (0.11%), illite (0.42%), and montmorillonite (1.68%). The amount of montmorillonite increased with depth. (1.68%). It is observed that the montmorillonite content slightly increases with depth.

Similarly, the overall Mae Sod Formation spans a depth range of approximately 2,500 to 9,200 feet. Based on data obtained from 39 samples, the mineral composition percentages are as follows: Quartz (17.97% to 82.20%, average 51.26%), Kaolinite (5.05% to 37.65%, average 17.68%), illite (1.75% to 17.66%, average 9.97%), chlorite (0.00% to 1.99%, average 0.99%), calcite (0.00% to 46.57%, average 6.83%), feldspar (3.91% to 17.49%, average 9.27%), and montmorillonite (0.59% to 8.90%, average 3.99%). The data indicates that the shale drill cuttings in the FA-SS-35-04 well are primarily composed of kaolinite, illite, montmorillonite, and chlorite. These clay mineral compositions show a slight increase with depth, particularly the montmorillonite, which is influenced by the shale swelling zone.

Furthermore, the average montmorillonite content varies across different units: 2.02% in Upper Unit A, 4.96% in Lower Unit A, 5.30% in Unit B, and 5.54% in Unit C. Consequently, there is an increasing trend of montmorillonite content with depth, specifically in upper unit A, Lower Unit A, Unit B, and Unit C. It is important to exercise caution while drilling through these depths due to these observations.

5.2 Predication swelling shale zone

Based on previous studies conducted in the Fang basin, specifically in the Mae Soon Oil Field (Suthera, 2017) and Fang Oil Field (Phiriya-anuphon, 2017) which are in close proximity to the study area, it was observed that drilling operations in these wells experienced pipe sticking due to the effect of the shale swelling zone. The shale swelling was found to be associated with the montmorillonite content, ranging from 4.92% to 6.77% (Phiriya-anuphon, 2017). Additionally, the montmorillonite content tends to increase with depth.

In the Mae Sod Formation of the FA-SS-35-04 well, which spans a depth range of approximately 2,600 to 9,200 feet, the mineral compositions are as follows: quartz ranges from 17.97% to 82.20% (average 51.26%), kaolinite ranges from 5.05% to 37.65% (average 17.68%), illite ranges from 1.75% to 17.66% (average 9.97%), chlorite ranges from 0% to 1.99% (average 0.99%), calcite ranges from 0% to 46.57% (average 6.83%), feldspar ranges from 3.91% to 17.49% (average 9.27%), and montmorillonite ranges from 0.59% to 8.90% (average 3.99%). The elemental compositions include Al_2O_3 ranging from 7.91% to 23.03% (average 14.02%), Fe_2O_3 ranging from 2.91% to 19.73% (average 8.67%), MgO ranging from 1.0% to 3.37% (average 2.35%), Na_2O_3 ranging from 2.21% to 7.80% (average 4.82%), and CaO ranging from 0.23% to 25.47% (average 4.82%).

Based on the logging data, it was observed that the amount of shale varied with depth. The shale volume showed an increasing trend with depth in Upper Unit A, a decreasing trend with depth in Lower Unit A, and an increasing trend with depth in Unit B and Unit C. Density and porosity data also exhibited an increasing trend with depth in Unit A.

The data indicates the predominant clay mineral compositions in Mae Sod Formation. The shale drill cuttings from the FA-SS-35-04 well are kaolinite, illite, montmorillonite, and chlorite. These clay mineral compositions show a slight increase with depth, particularly the montmorillonite, which is influenced by the shale swelling zone. Moreover, the average montmorillonite content is 2.02% in Upper Unit A, 4.96% in Lower Unit A, 5.30% in Unit B, and 5.54% in Unit C.

5.3 Recommendations

This recommendation of this study for further study which recommendations as follows.

5.3.1 Collect samples for experiments with interval depth and drill cuttings may deviate from the specified depth.

5.3.2 Test samples with another well in the San Sai Oil Field to correlate data and study with another data or method such as resistivity log.

5.3.3 Samples may have deteriorated from the preserving period.

5.3.4 Study the appropriate additives to reduce the efficiency of shale welling

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APPENDIX

APPENDIX A
EXPERIMENTAL DATA

Table A1 The results of mineral composition

formation	Unit	depth(ft.)	Mineral compositions (%)							Average value
			Q	K	Il	Ch	Ca	Feld	Mon	
Mae Fang	-	870	94.05	0.12	0.18	0.16	0.04	4.54	0.92	Q = 87.92%
		960	88.61	0.02	0.54	0	0.03	8.28	2.55	K = 0.11%
		1350	88.34	0.31	0.58	0.17	0.06	9.45	1.09	Il = 0.42%
		1830	89.91	0.16	0.5	0.04	0.03	7.64	1.72	Ch = 0.11%
		2100	84.51	0.23	0.37	0.18	0.08	12.27	2.37	Ca = 0.08%
		2160	84.74	0.06	0.45	0.05	0.14	12.86	1.7	Feld = 9.69%
		2260	85.85	0	0.5	0.21	0.1	11.22	2.12	Mon = 1.68%
		2350	87.35	0	0.26	0.1	0.13	11.22	0.93	
Mae Sod	upper unit A	2680	63.85	17.04	6.93	0.95	0.00	8.44	2.42	Q = 63.99%
		2790	66.30	16.24	6.89	0.91	0.00	7.62	2.05	K = 14.52%
		2820	82.20	5.05	1.75	0.16	0.02	10.26	0.59	Il = 7.04%
		2950	70.78	12.78	5.19	0.67	0.01	8.77	1.69	Ch = 0.63%
		2980	53.94	19.57	10.38	0.78	0.00	12.30	3.03	Ca = 0.02%
		3000	68.74	9.61	6.40	0.36	0.00	13.91	0.98	Feld = 11.75%
		3030	70.76	8.32	4.77	0.23	0.00	14.96	0.96	Mon = 2.02%
		3080	47.38	20.76	11.08	0.93	0.00	17.49	2.36	
		3150	75.22	6.53	6.26	0.00	0.00	9.48	2.51	
		3180	37.41	31.27	13.05	1.58	0.00	12.52	4.16	
		3220	77.44	8.19	3.56	0.30	0.21	9.45	0.85	
		3240	68.48	10.68	5.54	0.55	0.05	13.50	1.20	
		3270	64.54	12.76	7.26	0.49	0.02	13.31	1.62	
		3930	53.06	21.22	9.83	1.02	0.00	11.54	3.34	
		3980	59.75	17.77	6.66	0.59	0.00	12.72	2.51	
	Lower unit A	4020	62.11	16.46	6.67	0.99	0.00	11.03	2.75	Q =41.62%
		4110	46.67	26.47	8.63	1.24	0.00	12.73	4.25	K = 23.80%
		4140	46.67	26.47	8.63	1.24	0.00	12.73	4.25	Il = 11.53%
		4170	51.01	24.33	8.78	1.43	0.00	9.82	4.62	Ch = 1.33%
		4360	41.72	31.78	10.52	1.85	0.00	8.26	5.86	Ca = 8.05%
		4470	28.38	37.65	14.16	1.58	0.00	10.11	8.12	Feld = 9.04%
		4500	29.43	31.80	14.35	1.92	5.16	10.16	7.17	Mon = 4.96%
		4640	43.79	21.56	10.98	1.46	10.90	6.48	4.84	
		4740	36.14	16.23	17.66	1.75	19.51	3.91	4.79	
		4840	39.21	16.07	14.10	0.68	19.88	5.74	4.31	
		4940	32.67	12.94	12.40	0.48	33.09	4.77	3.65	
	Unit B	5830	19.93	15.73	10.51	0.56	45.36	4.91	2.99	Q = 28.37%, K = 13.68%
		6160	17.97	11.93	14.13	0.46	45.44	4.72	5.36	Il = 12.31%, Ch = 0.56%
		6280	23.36	12.52	8.48	0.68	46.57	4.22	4.17	Ch = 0.56%, Ca = 8.05%
		6450	39.58	10.36	11.84	0.47	27.27	5.42	5.06	Feld = 5.12%, Mon = 5.30%
		6700	41.03	17.84	16.60	0.63	8.70	6.31	8.90	
	Unit C	7110	29.17	33.20	14.60	1.35	0.42	13.16	8.10	Q = 54.96%
		7300	72.38	10.18	7.01	0.90	0.00	5.33	4.20	K = 17.70%
		8110	47.21	19.04	14.63	1.41	0.10	9.54	8.06	Il = 11.84%
		8120	48.17	18.86	16.35	1.30	0.46	8.00	6.87	Ch = 1.44%
		8680	58.36	15.40	11.97	1.78	0.79	6.72	4.98	Ca = 0.53%
		8730	53.43	15.83	12.02	1.76	1.71	9.60	5.66	Feld = 7.99%
		8830	72.31	10.56	6.82	1.02	0.77	5.81	2.70	Mon = 5.54%
		9150	58.62	18.53	11.31	1.99	0.00	5.77	3.78	

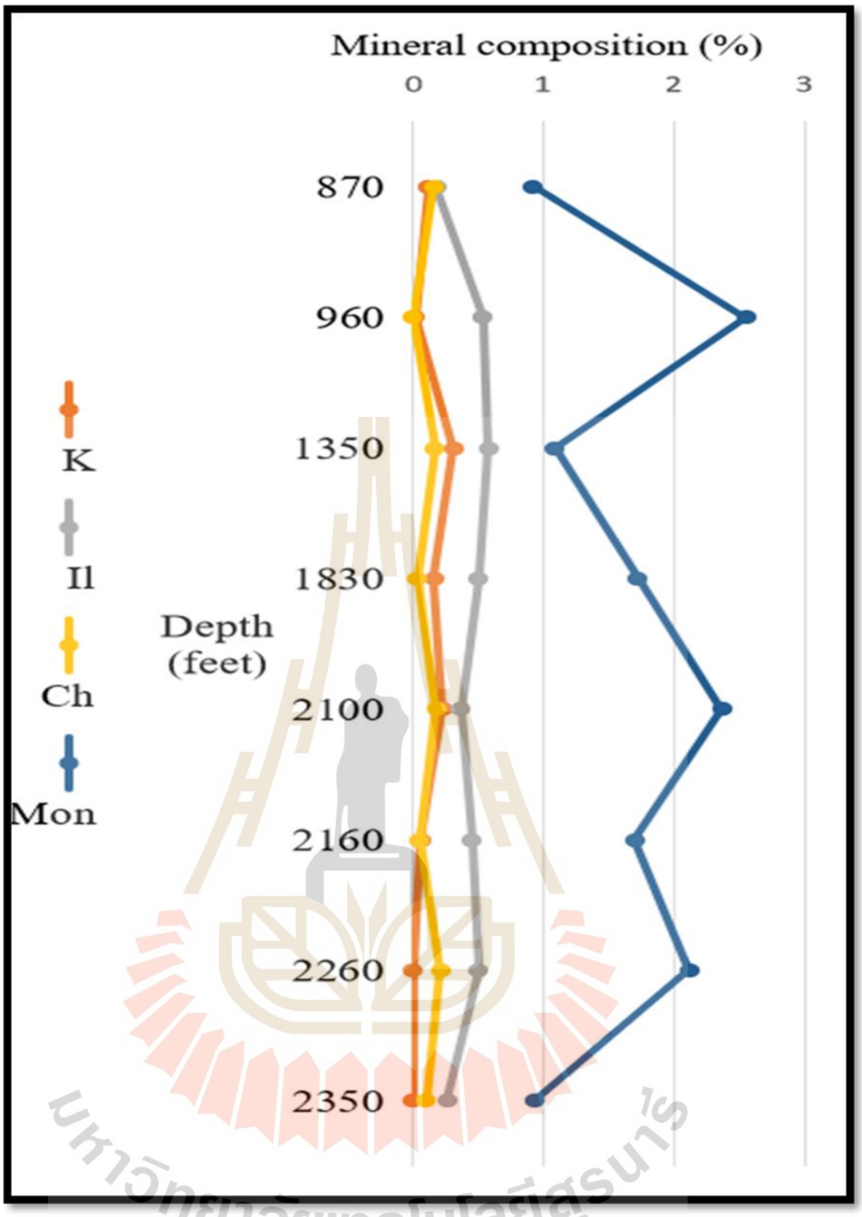

Figure A1 Mineral composition of Mae Fang Formation in FA-SS035-04 well.

Table A2 Mineral Composition of FA-SS-35-04 well.

formation	Unit	depth(ft.)	Mineral compositions (%)							Average value
			Q	K	Il	Ch	Ca	Feld	Mon	
Mae Fang	-	870	94.05	0.12	0.18	0.16	0.04	4.54	0.92	Q = 87.92%
		960	88.61	0.02	0.54	0	0.03	8.28	2.55	K = 0.11%
		1350	88.34	0.31	0.58	0.17	0.06	9.45	1.09	Il = 0.42%
		1830	89.91	0.16	0.5	0.04	0.03	7.64	1.72	Ch = 0.11%
		2100	84.51	0.23	0.37	0.18	0.08	12.27	2.37	Ca = 0.08%
		2160	84.74	0.06	0.45	0.05	0.14	12.86	1.7	Feld = 9.69%
		2260	85.85	0	0.5	0.21	0.1	11.22	2.12	Mon = 1.68%
		2350	87.35	0	0.26	0.1	0.13	11.22	0.93	
Mae Sod	upper unit A	2680	63.85	17.04	6.93	0.95	0.00	8.44	2.42	Q = 63.99%
		2790	66.30	16.24	6.89	0.91	0.00	7.62	2.05	K = 14.52%
		2820	82.20	5.05	1.75	0.16	0.02	10.26	0.59	Il = 7.04%
		2950	70.78	12.78	5.19	0.67	0.01	8.77	1.69	Ch = 0.63%
		2980	53.94	19.57	10.38	0.78	0.00	12.30	3.03	Ca = 0.02%
		3000	68.74	9.61	6.40	0.36	0.00	13.91	0.98	Feld = 11.75%
		3030	70.76	8.32	4.77	0.23	0.00	14.96	0.96	Mon = 2.02%
		3080	47.38	20.76	11.08	0.93	0.00	17.49	2.36	
		3150	75.22	6.53	6.26	0.00	0.00	9.48	2.51	
		3180	37.41	31.27	13.05	1.58	0.00	12.52	4.16	
		3220	77.44	8.19	3.56	0.30	0.21	9.45	0.85	
		3240	68.48	10.68	5.54	0.55	0.05	13.50	1.20	
		3270	64.54	12.76	7.26	0.49	0.02	13.31	1.62	
		3930	53.06	21.22	9.83	1.02	0.00	11.54	3.34	
		3980	59.75	17.77	6.66	0.59	0.00	12.72	2.51	
	Lower unit A	4020	62.11	16.46	6.67	0.99	0.00	11.03	2.75	Q =41.62%
		4110	46.67	26.47	8.63	1.24	0.00	12.73	4.25	K = 23.80%
		4140	46.67	26.47	8.63	1.24	0.00	12.73	4.25	Il = 11.53%
		4170	51.01	24.33	8.78	1.43	0.00	9.82	4.62	Ch = 1.33%
		4360	41.72	31.78	10.52	1.85	0.00	8.26	5.86	Ca = 8.05%
		4470	28.38	37.65	14.16	1.58	0.00	10.11	8.12	Feld = 9.04%
		4500	29.43	31.80	14.35	1.92	5.16	10.16	7.17	Mon = 4.96%
		4640	43.79	21.56	10.98	1.46	10.90	6.48	4.84	
		4740	36.14	16.23	17.66	1.75	19.51	3.91	4.79	
		4840	39.21	16.07	14.10	0.68	19.88	5.74	4.31	
		4940	32.67	12.94	12.40	0.48	33.09	4.77	3.65	
	Unit B	5830	19.93	15.73	10.51	0.56	45.36	4.91	2.99	Q = 28.37%, K = 13.68%
		6160	17.97	11.93	14.13	0.46	45.44	4.72	5.36	Il = 12.31%, Ch = 0.56%
		6280	23.36	12.52	8.48	0.68	46.57	4.22	4.17	Ch = 0.56%, Ca = 8.05%
		6450	39.58	10.36	11.84	0.47	27.27	5.42	5.06	Feld = 5.12%, Mon = 5.30%
		6700	41.03	17.84	16.60	0.63	8.70	6.31	8.90	
	Unit C	7110	29.17	33.20	14.60	1.35	0.42	13.16	8.10	Q = 54.96%
		7300	72.38	10.18	7.01	0.90	0.00	5.33	4.20	K = 17.70%
		8110	47.21	19.04	14.63	1.41	0.10	9.54	8.06	Il = 11.84%
		8120	48.17	18.86	16.35	1.30	0.46	8.00	6.87	Ch = 1.44%
		8680	58.36	15.40	11.97	1.78	0.79	6.72	4.98	Ca = 0.53%
		8730	53.43	15.83	12.02	1.76	1.71	9.60	5.66	Feld = 7.99%
		8830	72.31	10.56	6.82	1.02	0.77	5.81	2.70	Mon = 5.54%
		9150	58.62	18.53	11.31	1.99	0.00	5.77	3.78	

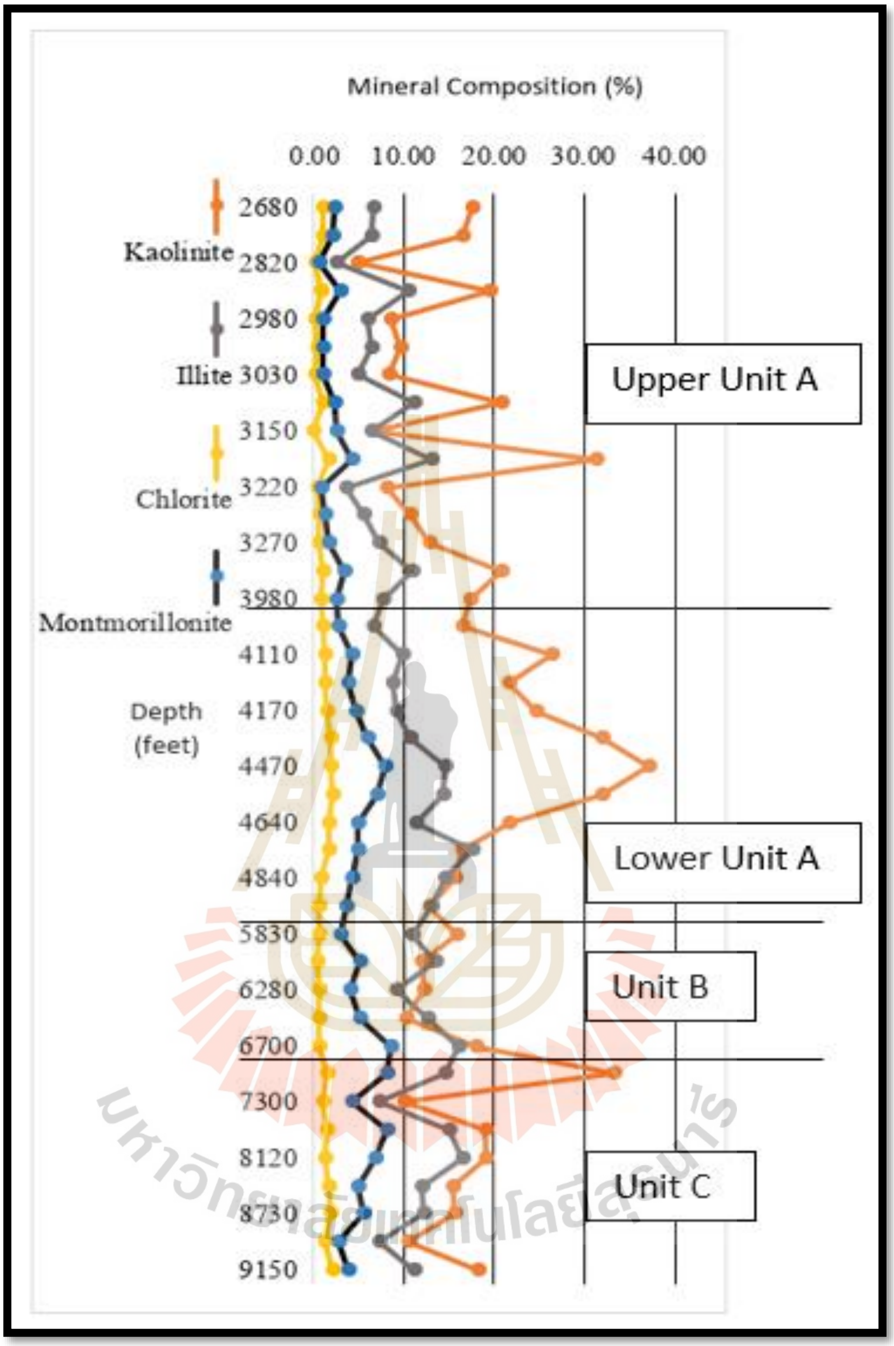

Figure A2 Mineral composition of Mae Sod Formation in FA-SS-35-04 well.

Table A3 The results of elemental composition.

Formation	Unit	Depth (ft.)	X-Ray Fluorescense (XRF) (%)												
			Na2O	MgO	Al2O3	SiO2	K2O	CaO	Cr2O3	MnO2	Fe2O3	NiO	TiO2	ZrO2	PbO
Mae Sod	Upper of unit A	2680	4.956	2.379	14.534	64.272	1.802	0.948	0.069	0.350	10.079	0.004	0.594	0.007	0.019
		2790	3.360	1.074	11.056	77.677	2.487	0.427	0.083	0.078	3.402	0.000	0.344	0.003	0.011
		2820	3.865	1.116	10.668	77.907	2.265	0.364	0.074	0.053	3.328	0.001	0.319	0.001	0.010
		2950	3.469	0.998	8.741	79.461	2.296	0.281	0.086	0.067	3.098	0.000	0.211	0.001	0.009
		2980	4.913	1.962	16.706	68.096	2.635	0.308	0.079	0.097	4.566	0.006	0.613	0.003	0.019
		3000	3.112	1.030	7.910	82.244	1.341	0.734	0.145	0.073	3.213	0.000	0.240	0.000	0.007
		3030	4.519	2.436	19.928	64.485	1.930	0.441	0.048	0.076	5.165	0.007	0.935	0.011	0.018
		3080	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
		3150	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
		3180	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
		3220	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
		3240	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
		3270	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
		3930	4.952	2.144	15.184	65.155	1.829	0.354	0.051	0.471	9.111	0.005	0.707	0.005	0.019
		3980	5.040	2.396	14.522	66.494	1.981	0.336	0.037	0.505	7.985	0.004	0.675	0.008	0.017
	Lower of unit A	4020	5.102	2.201	13.231	64.628	1.839	0.290	0.259	0.745	11.221	0.005	0.636	0.008	0.022
		4110	4.703	2.571	16.780	62.457	2.119	0.317	0.042	0.641	9.416	0.007	0.910	0.007	0.030
		4140	4.912	2.555	14.458	62.963	1.818	0.295	0.060	0.598	11.513	0.005	0.784	0.006	0.032
		4170	3.145	2.506	14.978	62.130	1.922	0.339	0.055	0.530	13.237	0.010	0.882	0.009	0.036
		4360	4.348	2.860	16.286	53.852	1.874	0.636	0.340	0.932	18.155	0.015	0.958	0.006	0.043
		4470	4.158	3.008	19.403	54.669	2.388	0.630	0.039	0.401	13.934	0.019	1.300	0.011	0.042
		4500	4.077	3.325	17.867	52.038	2.364	3.529	0.037	0.462	14.984	0.017	1.250	0.008	0.041
		4640	4.528	2.831	13.699	55.589	1.803	6.477	0.039	0.475	13.507	0.010	1.012	0.003	0.026
		4740	7.800	2.950	12.558	46.004	1.535	11.192	0.034	0.909	16.170	0.010	0.843	0.000	0.027
		4840	7.257	2.594	11.857	51.381	1.631	11.257	0.039	0.642	12.320	0.011	0.986	0.002	0.024
		4940	6.203	2.180	11.017	46.536	1.572	18.894	0.335	0.502	12.059	0.013	0.959	0.005	0.013
	Unit B	5830	2.213	2.247	11.706	35.445	1.602	25.472	0.042	0.415	19.729	0.015	1.097	0.004	0.012
		6160	6.340	2.938	11.202	33.490	1.547	24.264	0.041	0.383	18.715	0.016	1.052	0.004	0.007
		6280	5.849	2.694	13.837	47.770	1.211	20.746	0.037	0.155	6.871	0.012	0.807	0.004	0.007
		6450	6.462	2.977	13.261	56.767	1.128	11.151	0.030	0.287	7.264	0.005	0.656	0.001	0.013
		6700	4.454	2.949	17.310	59.126	1.484	4.326	0.029	0.212	9.314	0.007	0.770	0.003	0.015
	Unit C	7110	4.025	2.854	23.031	57.489	2.317	0.986	0.169	0.155	7.813	0.012	1.249	0.010	0.015
		7300	4.968	2.370	12.199	72.659	1.379	0.356	0.075	0.194	5.091	0.003	0.690	0.009	0.008
		8110	4.451	3.366	18.205	60.900	2.163	0.837	0.062	0.133	8.512	0.015	1.337	0.013	0.005
		8120	4.534	3.218	17.562	61.372	2.060	0.969	0.054	0.136	8.766	0.018	1.298	0.014	0.006
		8680	4.826	2.939	15.539	64.522	1.737	1.145	0.052	0.170	8.050	0.011	0.986	0.017	0.006
		8730	4.618	3.288	16.414	61.854	1.852	1.673	0.047	0.253	6.178	0.011	1.125	0.014	0.007
		8830	4.956	2.737	11.383	71.500	1.174	1.068	0.062	0.138	6.274	0.006	0.683	0.008	0.007
		9150	4.844	2.941	15.888	65.583	1.541	1.026	0.073	0.116	7.024	0.008	0.930	0.013	0.011

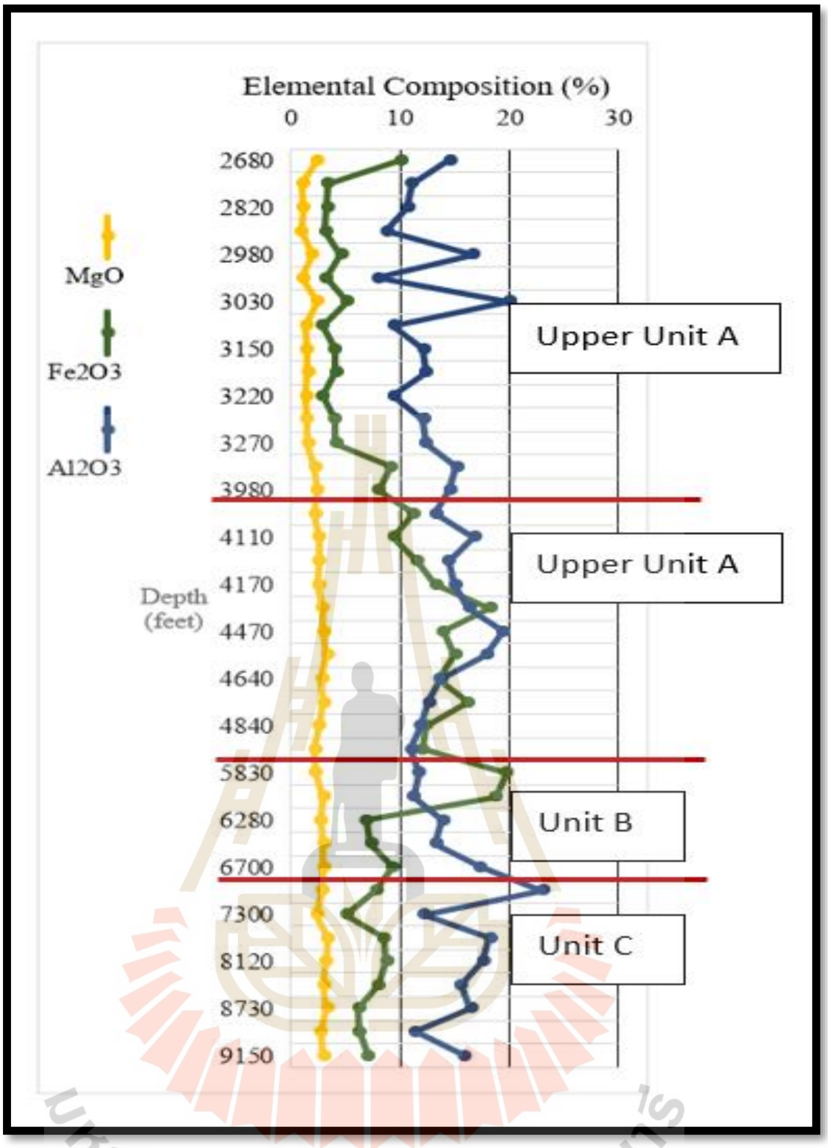

Figure A3 The elemental composition of Mae Sod Formation from FA-SS-35-04 well.

Table A4 The result of Scanning Electron Microscope (SEM) show flak sheet of clay mineral at 3180, 460, 4470, 6700, and 8110 ft.

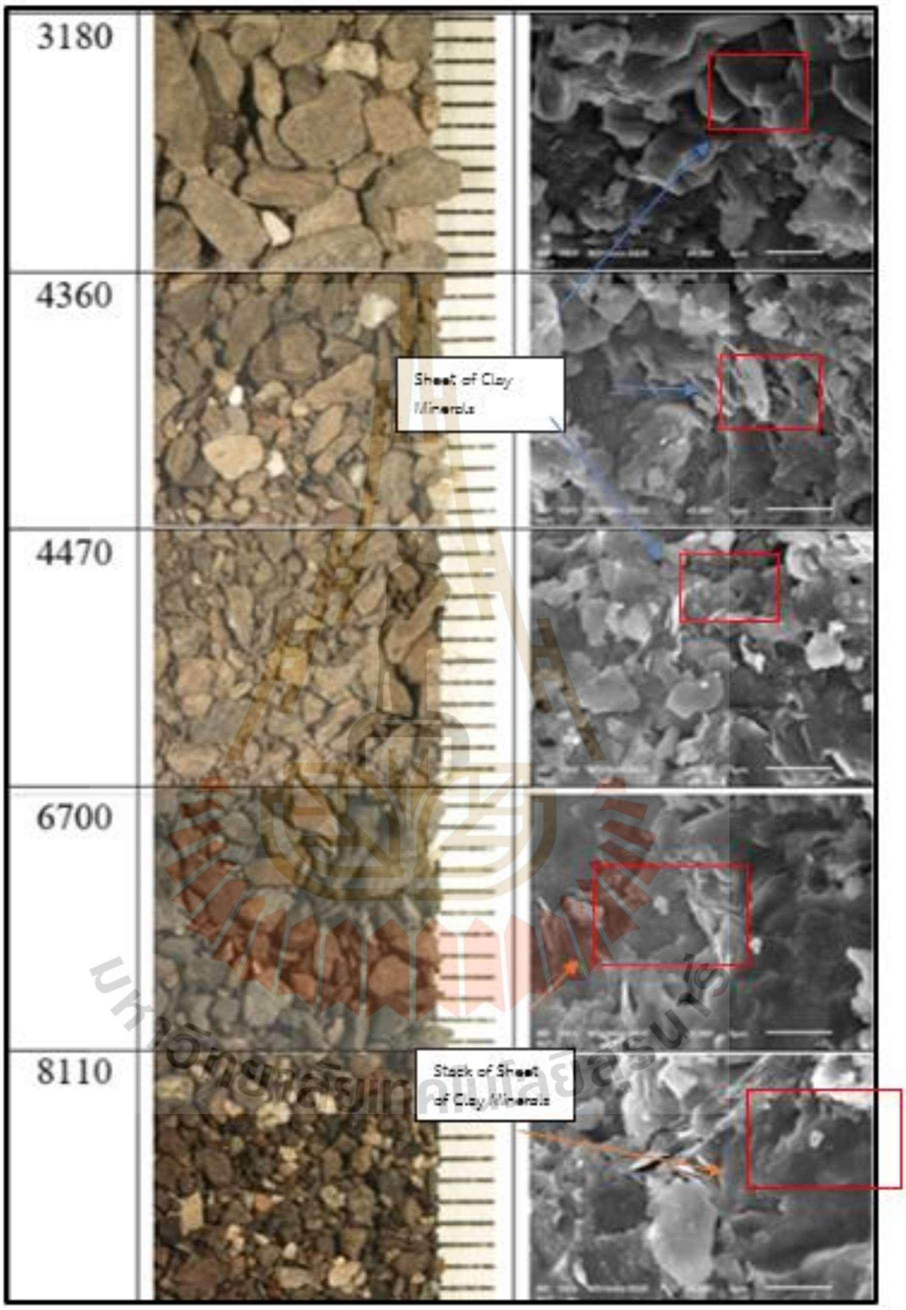

Table A5 The result of well log (Gamma-Ray), Density, Neutron.

Formation	Unit	Depth (ft.)	Gamma Ray log		Density log	Neutron log	Average
			API	Shale volume(%)	Density (g/cc)	PU (%)	
Mae Sod	Upper of unit A	2680	-	-	-	-	
		2790	-	-	-	-	
		2820	-	-	-	-	
		2950	212	0.516	2.15	5.00	
		2980	240	0.628	2.13	7.10	Shalve volume =56.3%
		3000	180	0.388	2.15	25.00	Density = 2.1 %
		3030	230	0.588	2.04	7.00	Neutron Porosity = 3.8-25%
		3080	125	0.168	2.16	20.00	
		3150	290	0.828	1.95	3.80	
		3180	275	0.768	2.17	5.00	
		3220	240	0.628	1.97	6.30	
		3240	245	0.648	2.00	4.10	
		3270	205	0.488	1.93	5.00	
		3930	238	0.620	2.35	5.00	
		3980	205	0.488	2.16	5.00	
	Lower of unit A	4020	220	0.725	2.00	8.80	
		4110	200	0.625	2.35	8.00	
		4140	220	0.725	2.27	6.80	
		4170	220	0.725	2.25	4.50	Shalve volume =55%
		4360	250	0.875	2.31	7.00	Density = 2.27 %
		4470	200	0.625	2.05	8.00	Neutron Porosity = 4.5-20%
		4500	185	0.550	2.2	6.80	
		4640	160	0.425	2.32	15.00	
		4740	140	0.325	2.45	17.00	
		4840	130	0.275	2.33	20.00	
		4940	110	0.175	2.43	10.00	
	Unit B	5830	120	0.222	-	-	
		6160	115	0.208	-	-	Shalve volume =28.6%
		6280	125	0.236	-	-	
		6450	135	0.264	-	-	
		6700	220	0.500	-	-	
	Unit C	7110	280	0.667	-	-	
		7300	150	0.306	-	-	
		8110	55	0.042	-	-	
		8120	140	0.278	-	-	Shalve volume =24.8%
		8680	70	0.083	-	-	
		8730	100	0.167	-	-	
		8830	110	0.194	-	-	
		9150	-	-	-	-	

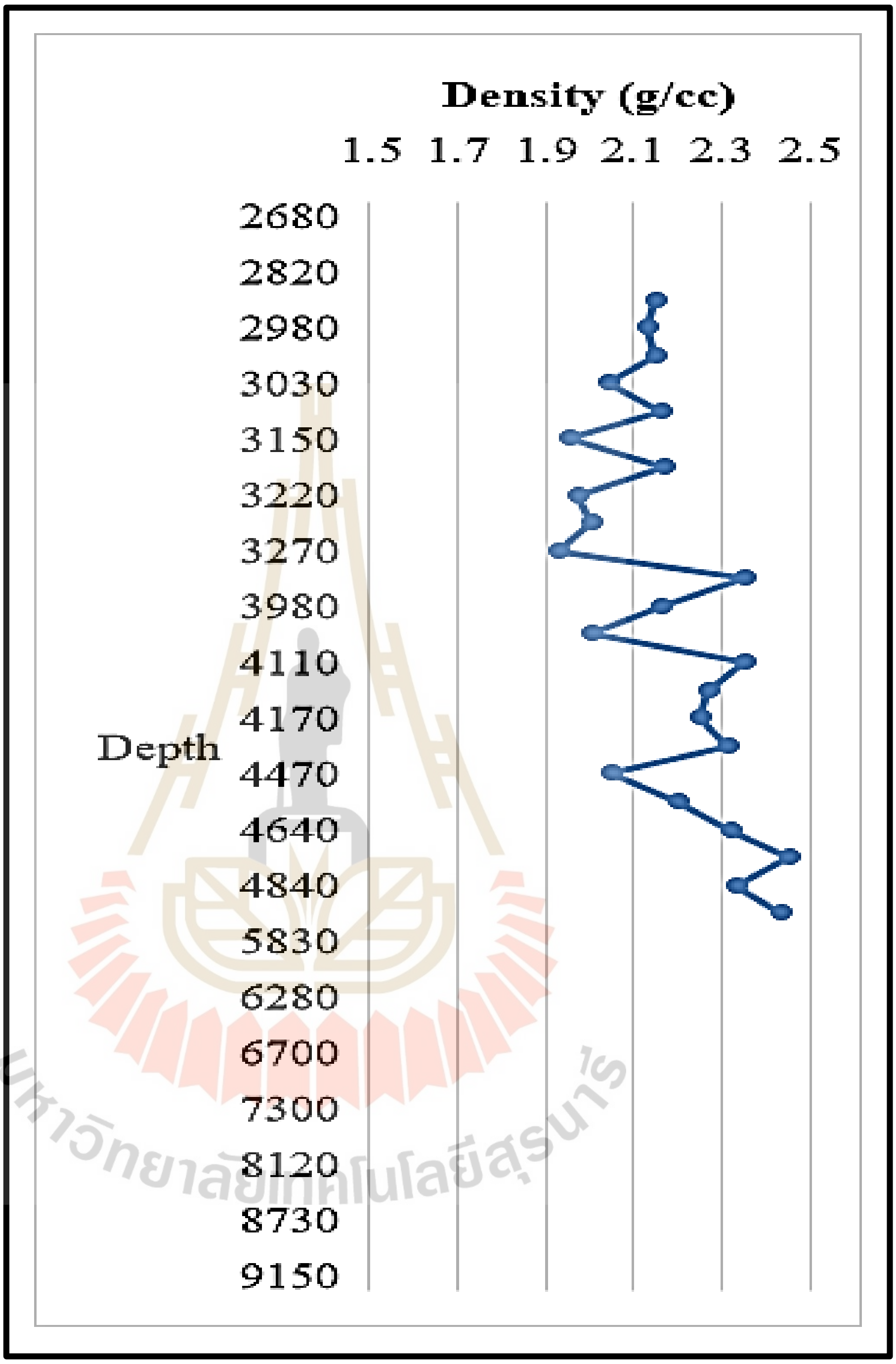

Figure A4 Density data from FA-SS-35-04 well.

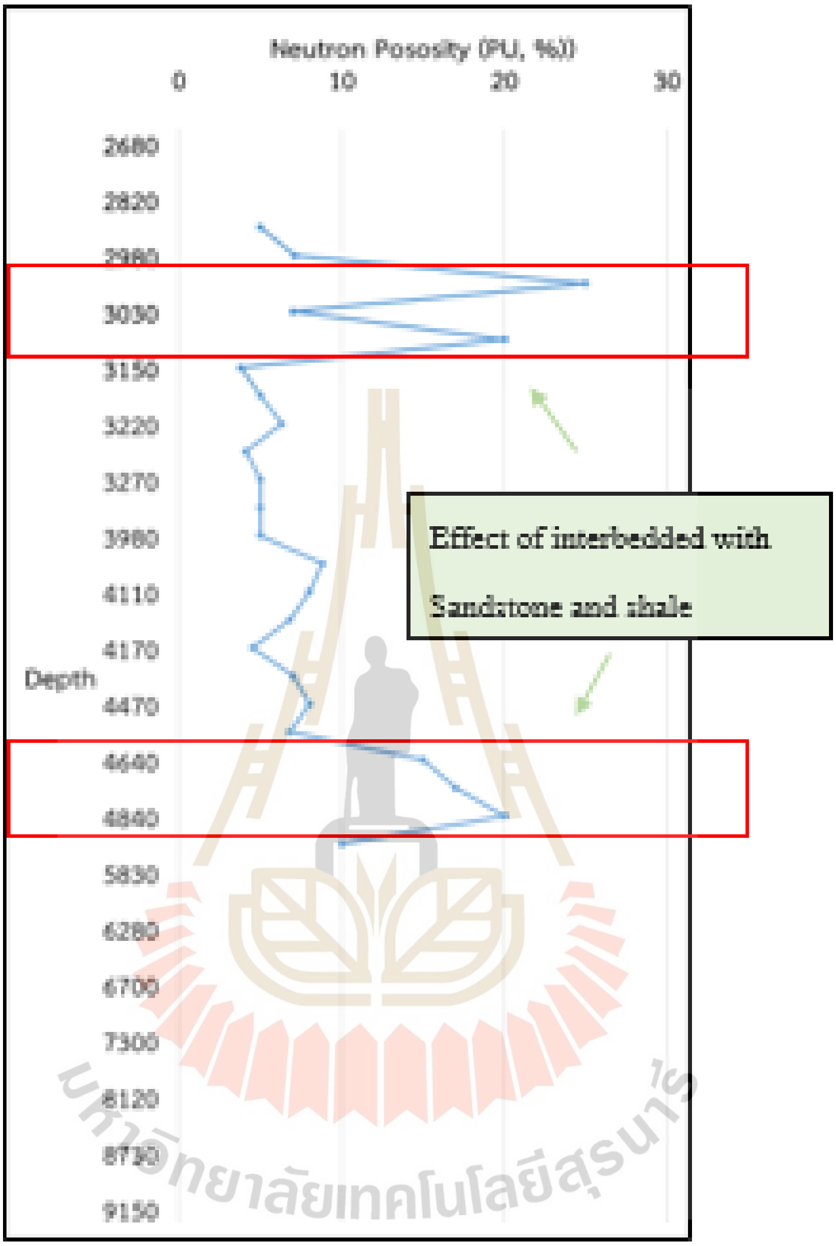

Figure A5 Neutron data from FA-SS-35-04 well.

APPENDIX B
PUBLICATION

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SWELLING SHALE ZONE PREDICTION USING THE RELATIONSHIP OF CLAY MINERAL AND SHALE VOLUME OF FANG BASIN, THAILAND

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ABSTRACT: Stuck pipe of the drilling string by shale swelling is one of the problems for petroleum drilling wells, especially in the Fang oil field, Thailand. The research objectives are to study the shale volume using gamma ray log, and the variation of clay mineral and elemental composition of drill cuttings of FA-SS-35-04 well to identify minerals and predict the swelling shale zone. The FA-SS-35-04 well is in the San Sai oil field, Fang Basin. The lithology of the basin can be divided into two formations including Mae Fang formation (~450-2,600 ft) and Mae Sod formation (~2,600-9,200 ft) based on drill cutting. 39 samples in Mae Sod formation are analyzed using gamma ray log data, X-ray diffraction, and X-Ray fluorescence. The gamma-ray value shows a high content of shale volume in clay layers. The results of clay mineral consist of 18.0-82.2% quartz (avg. 51.26%), 5.1-37.7% kaolinite (avg. 17.68%,), 1.8-17.7% illite (avg. 9.97%), 0-2.0% chlorite (avg. 0.99%), 0-46.6% calcite (avg. 6.83%), 3.9-17.5% feldspar (avg. 9.27%), and 0.6-8.9% montmorillonite (avg. 3.99%). The montmorillonite in all units of Mae Sod formation impacts directly shale swelling according to the increased depth, Al2O3, Fe2O3, and MgO contents. The lower zone (unit C) of this formation (especially 7,110-9,150 ft) represents the highest montmorillonite content which can affect shale swelling. Based on this shale swelling zone study, it can lead to forewarning and select the appropriate method to reduce and prevent the risk of stuck drill string or logging tools or formation caving problems during drilling operations in Fang basin.

Keywords: Clay Mineral, Shale Swelling, Shale volume, Montmorillonite, Fang Basin.

1. INTRODUCTION

Fang basin oil field is a tertiary basin located about 150 kilometers northwest of Chiang Mai province, Thailand and it is the first field that has been developed in Thailand [1]. The location of the Fang basin is shown in Fig. 1 [2,3].

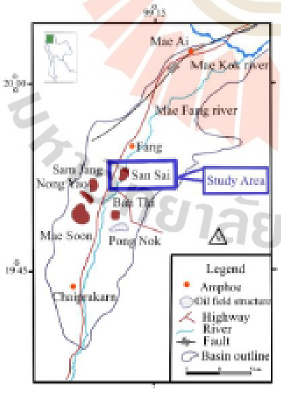

Fig 1. Fang Basin area (modified after Latt and Giao, (2012); Pitumwong (2011) [2,3].

Fang basin can be divided into two units consisting of Mae Fang and Mae Sod Formation.

The Mae Fang Formation (Pleistocene to Recent in age), 2,500 feet thick, is composed mainly of clay, coarse- to very coarse-grained sandstones, gravel and carbonized woods which were deposited in a fluvial environment. It overlies unconformably with the Mae Sod Formation. [4].

Mae Sod Formation (Middle Tertiary) is composed of brown to gray shale, yellowish mudstone generally interbedded with sand and sandstone with a series of channels of sand paleo-delta and fluvial sand [5].

One of the problems when drilling through shale formation in the Fang basin is a stuck drilling string caused by the swelling of shale [6,7]. Shales dominated by smectite (montmorillonite) minerals are highly reactive with aqueous fluids, causing swelling [8].

Generally, all the clay mineral types listed adsorb water, but smectites (montmorillonite) assimilate more into their structure than the other classes, in part due to their expanding lattice [9]. So, the variation of montmorillonite content is the main effect of this swell due to its clumping properties

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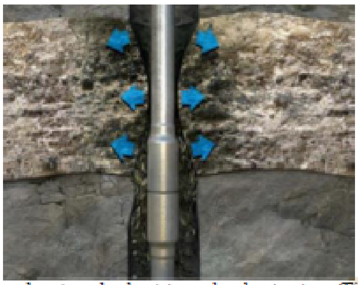

and water adsorbent to molecule structure (Fig. 2 and Fig. 3).

Fig 2. Stuck pipe in borehole [6].

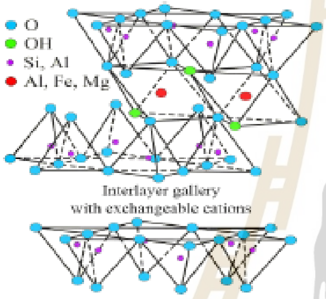

Fig 3. The structure of Montmorillonite clay [7].

From the previous study of shale swelling in Fang basin from FA-MS-61-95 well in Mae Soon oil field, the pipe stuck while the drilling operation occurred from the effect of shale swelling zone, whereas represented slightly increased montmorillonite content (4.92 to 6.77%) [10]. Moreover, the mineral composition study from FA-PK-60-09 well [11], Fang oil field, Fang basin (Fig. 1) represents the montmorillonite and illite tend to affect shale swelling [11]. Therefore, the objective of this research is to study the shale volume using gamma ray log and the variation of clay mineral and elemental composition of drill cuttings from FA-SS-35-04 well to identify minerals variation and predict swelling shale zone.

2. MATERIALS AND METHODOLOGY

2.1 Geological Background

FA-SS-35-04 well is in the San Sai oil field at latitude 19°52' 35'' N and longitude 99° 12' 12'' E. This well was drilled into the San Sai oil reservoir and the lithology to be drilled consists of Mae Fang formation and Mae Sod formation. The stratigraphy of FA-SS-35-04 well [12] is shown in Fig. 4

2.1.1 Mae Fang Formation

The sediment compositions of the Mae Fang formation are mainly sand, gravel, and clay. The sand is generally light gray to dark gray, coarse to very coarse-grained with some granules, and moderately sorted. The gravel is light gray to gray, with some coarse- to very coarse-grained and poorly sorted, sand. The clay is generally gray.

2.1.2 Mae Sod Formation

The main lithology of the Mae Sod formation is shale, mudstone, siltstone, and sandstone with some coal layers interbedded. The Mae Sod formation consists of 3 sub-units including sub-unit A, B, and C. There are 2 parts of sub-unit A as the upper part and the lower part. The upper part consists interbedded of shale and sandstone with clay dominant. Shale is characterized by gray to dark gray and brown color, whereas sandstone is generally light gray to gray color and is medium- to very coarse-grained and mostly well sorted. The upper part is interpreted to be the marginal lacustrine facies. The lower part of sub-unit A composes of thick dark gray, black, and brown shale with fine-grain sandstone intercalation and there are some coal layers interbedded. It represents the shallow to deep lacustrine facies.

Sub-unit B consists of extremely thick dark-gray shale, fine-grained sandstone, and coal. This lithological succession is interpreted to be deposited in low-energy conditions of freshwater paleo-lake. The products that accumulate in this environment are sedimentary rocks of lacustrine facies.

Sub-unit C consists of the lower part of sandstone and a coal bed interbedded with black shale and the upper part of approximately 200 ft thickness of coal beds and some sandstone. The sandstone of the upper part of sub-unit C is generally red and gray, fine to very coarse-grained with some layers of very clean sand. It represents marginal lacustrine facies.

2.2 Methodology

The methodology of this research can be divided into log interpretation and quantification of clay minerals. As part of log interpretation, the volumes of shale are calculated by the Gamma-ray (GR) log of the FA-SS-35-04 well. Thirty-nine drilling cutting samples from 2,600 to 9,200 ft depth of FA-SS-35-04 well emphasis on Mae Sod formation were analyzed using cutting sample petrographic analysis, X-ray powder diffraction (XRD), and X-ray fluorescence (XRF) in the Suranaree University of Technology for the quantification of clay mineral and elementary composition analysis of all tested samples.

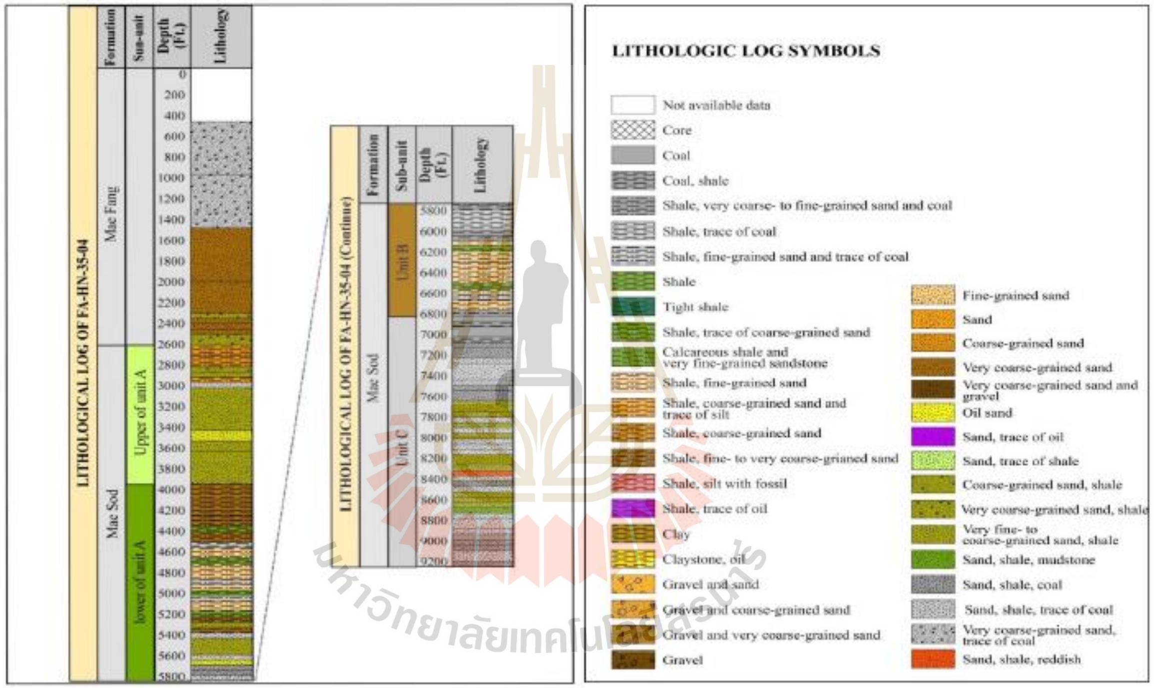

Fig 4. Lithological log of FA-SS-35-04 well [12].

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2.2.1 Shale volume

One of the clay quantificational predictions is shale volume calculation using a method of measuring naturally occurring gamma ray radiation to characterize the rock of sediment in a borehole. The shale volume is calculated using the linear method [13] as the following Eq. (1).

$$Vsh = (GRlog – GRmin) / (GRmax - GRmin) \quad (1)$$

Where, the GRlog = gamma-ray of the interesting zone, GRmin = minimum value of gamma-ray log, and GRmax = maximum value of the gamma-ray log.

2.2.2 Swelling shale

Clay minerals are composed of particles with small crystals, and they can be classified into different groups based on crystalline structure. Due to improper sorting in sedimentary environments, most sandstone reservoirs are containing clay minerals.

Shale can be usually divided into effective and non-effective shales. Effective shale, that rock referred to in the literature as shale is usually predominately the multilayer clays such as smectites (montmorillonite, bentonite, etc.) and illite. This shale has significant CEC (Cation exchange capacities) but, the non-effective shale, kaolinites, and chlorites have essentially very low CEC. Shale is the main problem in oil and gas drilling well. One problem is shale swelling, the effect of absorbing water from clay minerals such as montmorillonite causes stuck pipe and interpret logging [14] and the effect of shale can also result in erroneous values of water saturation and porosity as calculated from logs, especially effective shale. Therefore, the analyzed XRD for mineral composition and XRF techniques were used to analyze elemental composition to identify the quantity and types of clay minerals for all tested samples.

3. RESULTS AND DISCUSSION

The results from the FA-SS-35-04 well analysis to study shale volume, a rock-forming mineral of shale, and element association including upper and lower parts of sub-unit A, sub-unit B, and sub-unit C are presented in Table 1.

3.1 Shale volume

Based on Eq. (1) calculation, the shale volume of all samples varies from 0.42 to 8.75% for 2,820 to 9,150 feet depth (Fig. 5). The upper unit A has 16.80 to 80.28% of shale volume and the high shale volume values are at depth 3,150 and 3180 ft. The shale volume of lower unit A is 17.5 to 87.5% and the high shale volume values are at depths of 4,020, 4,140, 4,170, and 4,360 ft. The shale volume of unit B is between 2.08 and 50.0%, the high shale volume value is at depth of 6,700 ft. Unit C has 0.42 to 6.67% of shale volume and a high shale volume value at depth of 7,110 ft.

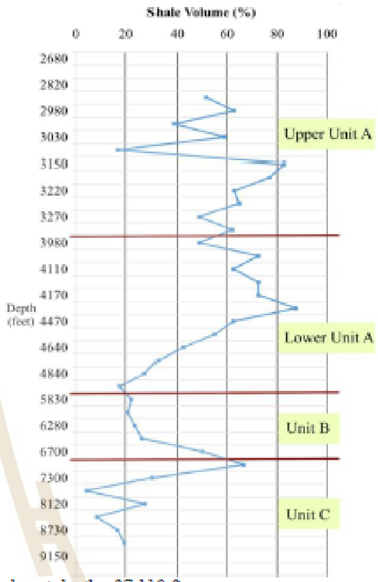

Fig 5. Shale volume of Mae Sod Formation of FA-SS-35-04 well.

3.2 Mineral and elemental composition

The composition of minerals from XRD and elements from XRF are shown in Table 1, Fig. 6, and Fig. 7, respectively. The study is focused on clay minerals, especially montmorillonite which causes shale swelling [7,12]. The result of elements of FA-SS-35-04 well of Fang basin deposit is given in Table 1 including Na_2O, MgO, Al_2O_3, Si_2O, K_2O, CaO, Cr_2O_3, MnO_2, Fe_2O_3, NiO, TiO_2, ZrO_2, and PbO. The Al_2O_3, Fe_2O_3, and MgO contents affect montmorillonite which relates to the shale swelling zone (Fig. 6).

Upper unit A: the clay mineral compositions are 37.41 to 82.20 % of quartz (avg. 63.99%), 5.05 to 31.27% of kaolinite (avg. 4.52%), 1.75 to 13.05% of illite (avg. 7.04%), 0 to 1.58% of chlorite (avg. 0.63%), 0 to 0.21% of calcite (avg. 0.02%), 7.62 to 17.49% of feldspar (avg. 11.75%), and 0.59 to 4.16% of montmorillonite (avg. 2.02%). The montmorillonite content is highest at 3,180 ft. The

Table 1 Result of study including shale volume, X-ray diffraction analysis, and X-Ray fluorescence from FA-SS-35-04 well.

NO.	Unit	Depth (ft.)	Gamma Ray log		X-Ray Diffraction (XRD) (%)							X-Ray Fluorescense (XRF) (%)												
			API	Shale volume(%)	Quartz	Kaolinite	Illite	Chlorite	Calcite	Felspar	Mont	Na2O	MgO	Al2O3	SiO2	K2O	CaO	Cr2O3	MnO2	Fe2O3	NiO	TiO2	ZrO2	PbO
1	Upper of unit A	2680	-	-	63.265	17.525	6.655	0.960	0.000	9.030	2.385	4.956	2.379	14.534	64.272	1.802	0.948	0.069	0.350	10.079	0.004	0.594	0.007	0.019
2		2790	-	-	65.845	16.455	6.335	0.915	0.000	8.415	2.040	3.360	1.074	11.056	77.677	2.487	0.427	0.083	0.078	3.402	0.000	0.344	0.003	0.011
3		2820	-	-	82.510	4.795	2.485	0.225	0.010	9.480	0.515	3.865	1.116	10.668	77.907	2.265	0.364	0.074	0.053	3.328	0.001	0.319	0.001	0.010
4		2950	212	0.516	53.940	19.570	10.380	0.780	0.000	12.300	3.030	3.469	0.998	8.741	79.461	2.296	0.281	0.086	0.067	3.098	0.000	0.211	0.001	0.009
5		2980	240	0.628	68.420	8.510	5.870	0.170	0.000	16.030	1.000	4.913	1.962	16.706	68.096	2.635	0.308	0.079	0.097	4.566	0.006	0.613	0.003	0.019
6		3000	180	0.388	68.740	9.610	6.400	0.360	0.000	13.910	0.980	3.112	1.030	7.910	82.244	1.341	0.734	0.145	0.073	3.213	0.000	0.240	0.000	0.007
7		3030	230	0.588	70.760	8.320	4.770	0.230	0.000	14.960	0.960	4.519	2.436	19.928	64.485	1.930	0.441	0.048	0.076	5.165	0.007	0.935	0.011	0.018
8		3080	125	0.168	47.380	20.760	11.080	0.930	0.000	17.490	2.360	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
9		3150	290	0.828	75.220	6.530	6.260	0.000	0.000	9.480	2.510	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
10		3180	275	0.768	37.410	31.270	13.050	1.580	0.000	12.520	4.160	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
11		3220	240	0.628	77.440	8.190	3.560	0.300	0.210	9.450	0.830	4.945	1.379	9.400	78.332	1.282	1.262	0.077	0.064	2.907	0.000	0.315	0.001	0.008
12		3240	245	0.648	68.480	10.680	5.540	0.550	0.050	13.500	1.200	5.389	1.482	12.108	73.972	2.106	0.371	0.088	0.115	3.988	0.001	0.370	0.000	0.011
13		3270	205	0.488	64.540	12.760	7.260	0.490	0.020	13.310	1.620	5.119	1.552	12.376	74.056	1.947	0.229	0.082	0.103	4.080	0.001	0.440	0.004	0.011
14		3930	238	0.620	54.075	20.755	10.810	1.075	0.000	10.040	3.255	4.952	2.144	15.184	65.155	1.829	0.354	0.051	0.471	9.111	0.005	0.707	0.005	0.019
15		3980	205	0.488	60.375	17.265	7.550	0.750	0.000	11.600	2.440	5.040	2.396	14.522	66.494	1.981	0.336	0.037	0.505	7.985	0.004	0.675	0.008	0.017
16	Lower of unit A	4020	220	0.725	62.110	16.460	6.665	0.985	0.000	11.025	2.750	5.102	2.201	13.231	64.628	1.839	0.290	0.259	0.745	11.221	0.005	0.636	0.008	0.022
17		4110	200	0.625	47.310	26.420	9.830	1.215	0.000	11.105	4.115	4.703	2.571	16.780	62.457	2.119	0.317	0.042	0.641	9.416	0.007	0.910	0.007	0.030
18		4140	220	0.725	55.485	21.665	8.705	1.220	0.000	9.170	3.745	4.912	2.555	14.458	62.963	1.818	0.295	0.060	0.598	11.513	0.005	0.784	0.006	0.032
19		4170	220	0.725	51.600	24.640	9.235	1.340	0.000	8.570	4.610	3.145	2.506	14.978	62.130	1.922	0.339	0.055	0.530	13.237	0.010	0.882	0.009	0.036
20		4360	250	0.875	41.405	32.005	10.665	1.955	0.000	8.125	5.835	4.348	2.860	16.286	53.832	1.874	0.636	0.340	0.932	18.155	0.015	0.958	0.006	0.043
21		4470	200	0.625	28.380	37.050	14.500	1.895	0.000	10.270	7.905	4.158	3.008	19.403	54.669	2.388	0.630	0.039	0.401	13.934	0.019	1.300	0.011	0.042
22		4500	185	0.550	28.970	32.000	14.360	2.105	5.075	10.395	7.095	4.077	3.325	17.867	52.038	2.364	3.529	0.037	0.462	14.984	0.017	1.250	0.008	0.041
23		4640	160	0.425	43.420	21.685	11.370	1.585	10.670	6.450	4.830	4.528	2.831	13.699	55.589	1.803	6.477	0.039	0.475	13.507	0.010	1.012	0.003	0.026
24		4740	140	0.325	35.495	16.550	17.580	1.645	19.395	4.560	4.765	7.800	2.950	12.558	46.004	1.535	11.192	0.034	0.909	16.170	0.010	0.843	0.000	0.027
25		4840	130	0.275	39.605	15.558	14.578	0.700	19.825	5.050	4.220	7.257	2.594	11.857	51.381	1.631	11.257	0.039	0.642	12.320	0.011	0.986	0.002	0.024
26		4940	110	0.175	33.080	12.705	12.940	0.550	33.110	4.050	3.565	6.203	2.180	11.017	46.536	1.572	18.894	0.335	0.502	12.059	0.013	0.959	0.005	0.013
27	Unit B	5830	120	0.222	20.215	15.725	10.965	0.525	45.290	4.300	2.970	2.213	2.247	11.706	35.445	1.602	25.472	0.042	0.415	19.729	0.015	1.097	0.004	0.012
28		6160	115	0.208	17.825	11.940	13.370	0.410	45.820	5.485	5.155	6.340	2.938	11.202	33.490	1.547	24.264	0.041	0.383	18.715	0.016	1.052	0.004	0.007
29		6280	125	0.236	22.975	12.190	9.115	0.575	46.450	4.715	3.985	5.849	2.694	13.837	47.770	1.211	20.746	0.037	0.155	6.871	0.012	0.807	0.004	0.007
30		6450	135	0.264	39.950	10.130	12.690	0.480	27.225	4.500	5.025	6.462	2.977	13.261	56.767	1.128	11.151	0.030	0.287	7.264	0.005	0.656	0.001	0.013
31		6700	220	0.500	40.650	17.885	15.950	0.505	8.835	7.610	8.560	4.454	2.949	17.310	39.126	1.484	4.326	0.029	0.212	9.314	0.007	0.770	0.003	0.015
32	Unit C	7110	280	0.667	29.170	33.200	14.600	1.350	0.420	13.160	8.100	4.025	2.854	23.031	57.489	2.317	0.986	0.169	0.155	7.813	0.012	1.249	0.010	0.015
33		7300	150	0.306	72.590	10.120	7.135	0.985	0.000	4.980	4.195	4.968	2.370	12.199	72.659	1.379	0.356	0.075	0.194	5.091	0.003	0.690	0.009	0.008
34		8110	55	0.042	46.970	19.010	14.905	1.360	0.140	9.635	7.980	4.451	3.366	18.205	60.900	2.163	0.837	0.062	0.133	8.512	0.015	1.337	0.013	0.005
35		8120	140	0.278	47.750	19.145	16.370	1.135	0.485	8.265	6.850	4.534	3.218	17.562	61.372	2.060	0.969	0.054	0.136	8.766	0.018	1.298	0.014	0.006
36		8680	70	0.083	57.500	15.400	11.875	1.650	0.925	7.695	4.955	4.826	2.939	15.539	64.522	1.737	1.145	0.052	0.170	8.050	0.011	0.986	0.017	0.006
37		8730	100	0.167	54.500	15.505	12.255	1.960	1.515	8.670	5.605	4.618	3.288	16.414	61.854	1.852	1.673	0.047	0.253	6.178	0.011	1.125	0.014	0.007
38		8830	110	0.194	72.755	10.555	7.150	1.135	0.635	5.085	2.675	4.956	2.737	11.383	71.500	1.174	1.068	0.062	0.138	6.274	0.006	0.683	0.008	0.007
39		9150	-	-	58.030	18.135	11.190	2.005	0.130	6.740	3.770	4.844	2.941	15.888	65.583	1.541	1.026	0.073	0.116	7.024	0.008	0.930	0.013	0.011

Note: ft= feet, Vsh = Shale volume, Mont = Montmorillonite

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content of elemental composition in this montmorillonite zone is slightly increased with depth including 7.91 to 19.93% of Al_2O_3 (avg. 12.47%), 2.91 to 10.08% of Fe_2O_3 (avg. 4.79%), and 1.00 to 2.44% of MgO (avg. 1.62%).

Lower unit A: the clay mineral compositions are 28.38 to 62.11% of quartz (avg. 41.62%), 12.94 to 37.65% of kaolinite (avg. 23.80%), 6.67 to 17.66% of illite (avg. 11.53%), 0.48 to 1.92% of chlorite (avg. 1.33%), 0 to 33.09% of calcite (avg. 8.05%), 3.91 to 12.73% of feldspar (avg. 9.04%), and 2.75 to 8.12% of montmorillonite (avg. 9.04%). The montmorillonite content is stable or slightly increased with depth and high value at 4,360, 4,470, and 4,470 ft, respectively. The content of elemental composition in this montmorillonite zone is slightly increased with depth including 11.02 to 19.40% of Al_2O_3 (avg. 14.74%), 9.42 to 10.08% (avg. 4.79%) of Fe_2O_3, and 2.18 to 3.33% of MgO (avg. 2.69%).

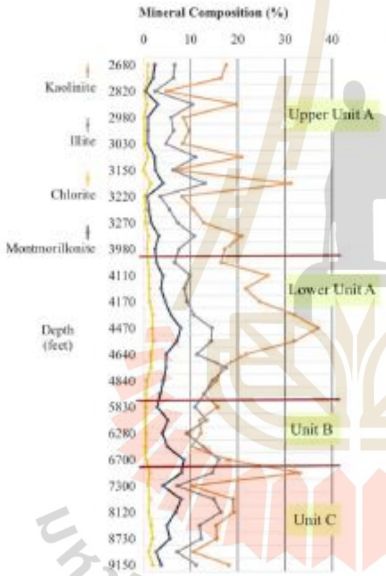

Fig 6. Clay mineral composition of Mae Sod Formation.

Unit B: the clay mineral compositions are 7.97 to 41.03% of quartz (avg. 28.37%), 10.18 to 17.84% of kaolinite (avg. 13.68%), 8.48 to 16.60% of illite (avg. 12.31%), 0.46 to 0.68% of chlorite (avg. 0.56%), 8.70 to 46.57% of calcite (avg. 34.67%), 4.22 to 6.31% of feldspar (avg. 5.12%), and 2.99 to 8.90% of montmorillonite (avg. 5.30%). The montmorillonite content is the highest value at 6,700 ft. The content of elemental composition in this montmorillonite zone is slightly increased with depth including 11.2 to 59.3% (avg. 13.46%) of Al_2O_3. 6.87 to 19.73% of Fe_2O_3 (avg. 12.38%), and 2.21 to 2.98% of MgO (avg. 2.76%).

Unit C: the content of clay mineral is 29.17 to 72.38% of quartz (avg. 54.96%), 10.18 to 33.20% of kaolinite (avg. 17.70%), 6.82to 16.35% of illite (avg. 11.84%), 0.90 to 1.99% of chlorite (avg. 1.44%), 0 to 1.71% of calcite (avg. 0.53%), 5.33 to 13.16% of feldspar (avg. 7.99%), and 2.70 to 8.10% of montmorillonite (avg. 5.54%). The montmorillonite content is slightly decreased with the depth and the high value are at 7,110 and 8,110 ft, respectively. The content of elemental composition in this montmorillonite zone is slightly increased with depth including 11.38 to 23.03% of Al_2O_3 (avg. 16.28), 5.09 to 8.77% of Fe_2O_3 (avg. 7.21%), and 2.37 to 3.37% of MgO (avg. 2.96%).

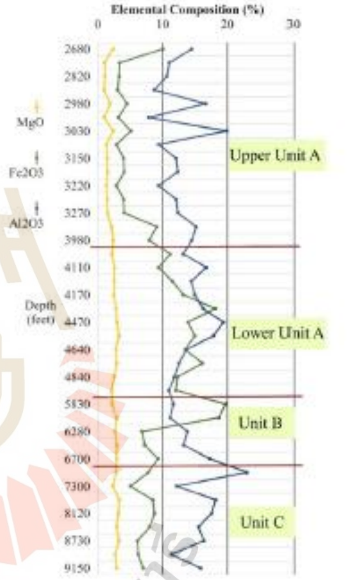

Fig 7. Elemental composition with depth on Mae Sod Formation.

3.3 Prediction of swelling shale zone

Based on the previous study of shale swelling of Fang basin from FA-MS-61-95 well in Mae Soon oil field [8], and FA-PK-60-09 well, Fang oil field, [9], whereas nearby this study area. These well represented that the pipe stuck while the drilling operation occurred from the effect of the shale swelling zone, which is related to montmorillonite content (4.92 to 6.77%) [8], and montmorillonite

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tends to increase with depth [9].

Based on the results of mineral and elemental contents of Mae Sod formation from FA-SS-35-04 well has approximately 2,600 to 9,200 ft of depth. The mineral compositions are 17.97 to 82.20% of quartz (avg. 51.26%), 5.05 to 37.65% of kaolinite (avg. 17.68%,), 1.75 to 17.66% of illite (avg. 9.97%), 0 to 1.99% of chlorite (avg. 0.99%), 0 to 46.57% of calcite (avg. 6.83%), 3.91 to 17.49% of feldspar (avg. 9.27%), and 0.59 to 8.90% of montmorillonite (avg. 3.99%). The content of elemental compositions is 7.91 to 23.03% (avg. 4.02%) of Al_2O_3, 2.91 to 19.73% (avg. 8.67%) of Fe_2O_3, and 1.0 to 3.37% (avg. 2.35%) of MgO. The data reveals that the most of quantity of clay mineral composition of shale drill cuttings from FA-SS-35-04 well are kaolinite, illite, montmorillonite, and chlorite. These clay mineral compositions are slightly increased with depth, especially the montmorillonite affected by the shale swelling zone. Moreover, the average montmorillonite content represents 2.02 % of upper unit A, 4.96% of lower unit A, 5.30% of unit B, and 5.54% of unit C.

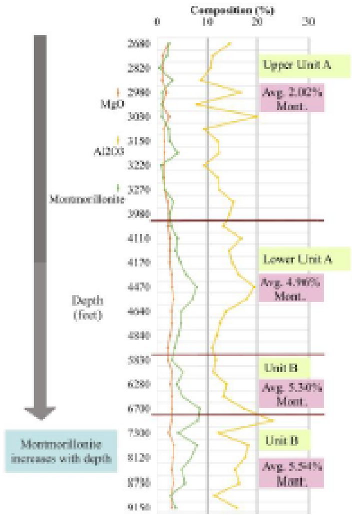

Fig 8. The high content of the montmorillonite zone.

4. CONCLUSIONS

The ranges of shale volume in Mae Sod formation are 17 to 88% based on the estimated by GR log, and thirty-nine drill cuttings of Mae Sod formation from FA-SS-35-04 well were also analyzed by XRD and XRF, respectively. The analyzed results represented 4 types of clay minerals including kaolinite (5.05 to 37.65%), illite (1.75 to 17.66%), chlorite (0 to 1.99%), and montmorillonite (0.59 to 8.9%). This montmorillonite impacts significantly shale swelling, which it represents in all units of the Mae Sod formation increasing with depth. The result showed that the increase of montmorillonite was associated with an increase of Al_2O_3, Fe_2O_3, and MgO.

The trend of montmorillonite content increases with depth according to the upper and lower of unit A, unit B, and unit C, respectively. As the montmorillonite content is more than 4.92% [10]. It could be caused to the swelling shale zone. This high content of montmorillonite relates to the shale layer of unit C (at 7,170, 8,180, 8,120, 8,680, and 8,730 ft depth) tends to be more swollen than unit B (at 6,160, 6,450, and 6,700 ft depth), lower unit A (at 3,180 ft. depth), respectively. In summary of this study, the lower zone (units C and B) of the Mae Sod formation could be aware of shale swelling while drilling operations. According to the results, it can be used as a prerequisite for planning to drill through this formation in the Fang basin area for the future drilling well.

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Variation of Clay Mineral Composition in Swelling Shale Zone of Mae Sod Formation from San Sai Oil Field, Fang Basin

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Abstract. San Sai oil field (FA-SS-35-04 well) whereas the one of petroleum well located in Fang basin, Chiang Mai province. The lithology can be divided into two formations consist of Mae Fang formation (~450-2600 ft) and Mae Sod formation (~2600-9200 ft). One important problem is shale swelling through shale in Mae Sod formation (upper unit A, lower unit A, unit B and unit C). The studied objective is to study the variation of clay mineral composition of drill cuttings from FA-SS-35-04 well to identify minerals variation and predict swelling shale zone. All samples in Mae Sod formation were analyzed by X-ray diffraction. The results of clay mineral consist of 17.97 to 82.20% of quartz (Avg. 51.26%), 5.05 to 37.65% of kaolinite (Avg. 17.68%,), 1.75 to 17.66% of illite (Avg. 9.97%), 0.00 to 1.99% of chlorite (Avg. 0.99%), 0.00 to 46.57% of calcite (Avg. 6.83%), 3.91 to 17.49% of feldspar (Avg. 9.27%), and 0.59 to 8.90% of montmorillonite (Avg. 3.99%). The especially montmorillonite more impact on shale swelling, which it represents in all units of Mae Sod formation increasing with depth. According to this result, the lower zone of this formation could be aware of shale swelling. This indicates that the shale layer of unit C tends to be swollen than unit B, lower unit A, and upper unit A, respectively.

Keywords: shale swelling, montmorillonite, drill cutting.

1. Introduction

The Fang basin is located in Chiang Mai province, Northern Thailand (Figure 1). The Fang basin is intermontane basin which has a half-graben geometry [1]. Its lithology can be divided into 2 formations consist of Mae Fang formation and Mae Sod formation.

Mae Fang formation (Pleistocene age) consists of gravel sand and mud of fluvial deposits, the arkosic sand consists of quartz, feldspar, and mica, which represents a large scale cross-bedded. From the seismic data, Mae Fang formation is thicker in the western and central of the basin, and decline to east direction. The structure of the Mae Fang formation shows the stream channels and flowed from south to north [2].

The Mae Sod formation (Middle Tertiary) is composed of brown to gray shale, yellowish mudstone generally interbedded with sand and sandstone with a series of channels of sand paleo-delta and fluvial sand [3].

During drill through shale layers in Mae Sot formation, one of the problems with the sticking of the drill pipe caused by the swelling shale. The clay mineral is the main effect of this swell which especially montmorillonite. Because of its clumping properties and water adsorbent to molecule structure (Figure 2). From the previous study of shale swelling from FA-MS-61-95 well in Mae Soon oil field, Fang basin by Phiriya-anuphon (2017) [4] reported that the pipe stuck while the drilling operation occurred from effect of shale swelling zone, whereas represented slightly increased montmorillonite content (4.92 to 6.77%). Therefore, the objective of this research is to study the variation of clay mineral composition of drill cuttings from FA-SS-35-04 well to identify minerals variation and predict swelling shale zone.

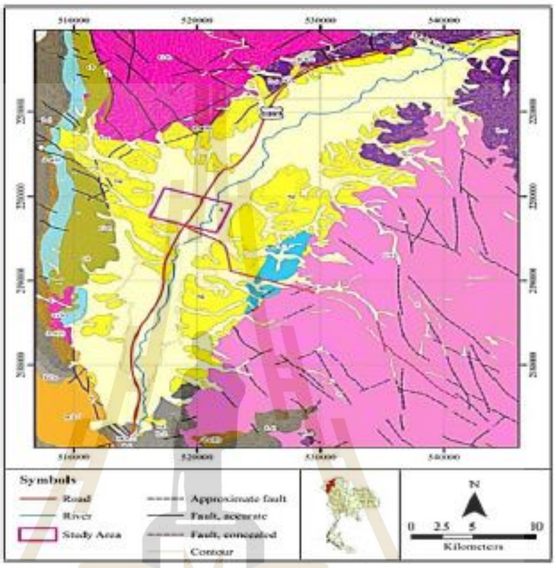

Figure 1. Located of Fang basin [1].

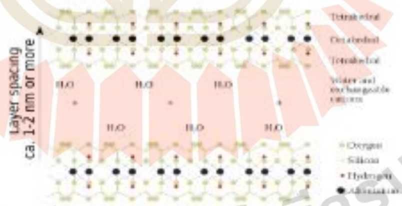

Figure 2. Structure of montmorillonite [5]

2. Stratigraphy of FA-SS-35-04 well

The formation of the FA-SS-35-04 well can be divided into two formations consist Mae Fang formation and Mae Sod formation [6]. The stratigraphy is shown in Figure 3.

2.1 Mae Fang formation (~450-2600 ft)

The sand is generally light to dark gray, coarse- to very coarse-grained with some granule and moderately sorting. The gravel is light gray to gray, with some coarse- to very coarse-grained and poorly sorting. The clay is generally gray.

2.2 Mae Sod formation (~2600 – 9200 ft)

Sub-unit A: The unit can be divided into two parts. The upper part consists interbedded of shale and sandstone with shale dominant. The sediment mainly represents a gray to dark gray and brown shale, whereas the sandstone is generally light gray to gray color and is medium- to very coarse-grained and mostly well sorted. This part is interpreted to be the marginal lacustrine facies.

The lower part is composed of thick shale with fine-grained sandstone intercalations. The shale is characterized by dark gray, black and dark brown color and with some coal layers. It represents shallow to deep lacustrine facies.

Sub-unit B: The unit consists of extremely thick dark to gray shale, fine-grained sandstone, and coal. This lithological succession is interpreted to be deposited in a low-energy condition of freshwater paleo-lake. The products that accumulate in this environment are sedimentary rocks of lacustrine facies.

Sub-unit C: The lower part of the unit consists of a sandstone and coal bed interbedded with black shale. The upper part comprises coal beds approximately 200 feet thick and some sandstone. Sandstone is generally red and gray, fine to very coarse-grained sandstone with some layers of very clean sand. It represents marginal lacustrine facies.

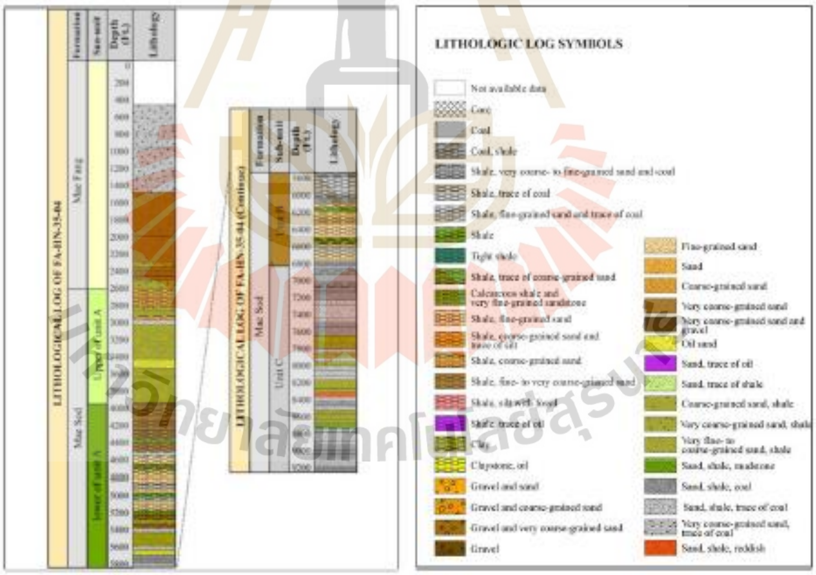

Figure 3. Lithological log of FA-SS-35-04 well [6].

3. Methodology

Thirty-nine cutting samples of Mae Sod formation from FA-SS-35-04 well consist of 15 samples of upper unit A, 11 samples of lower unit A, 5 samples of unit B, and 8 samples of unit C. All of the samples were prepared to grind by ball mill machine and tested the mineral composition at the Suranaree University of technology. The mineral composition of shale was measure with the X-ray diffraction Diffractometer-D8 (XRD-D8) according to scanning of 40 kV/ 40 mA, 2° to 60°2Θ at 0.02° min^{-1}, and Cu X-ray tube. The XRD result of the data was analyzed with the Topaz program.

4. Results and Discussion

The result of mineral association on a variety of depth is shown in Table and Figure 4. The study is especially focused on montmorillonite (Figure 5) that cause shale swelling [7].

4.1 Upper unit A

The upper unit A has approximately 2600 to 3980 feet. The percentage of mineral compositions are 37.41 to 82.20 % of quartz (Avg. 63.99%), 5.05 to 31.27% of kaolinite (Avg.14.52%), 1.75 to 13.05% of illite (Avg. 7.04%), 0.00 to 1.58% of chlorite (Avg. 0.63%), 0.00 to 0.21% of calcite (Avg. 0.02%), 7.62 to 17.49% of feldspar (Avg. 11.75%), and 0.59 to 4.16% of montmorillonite (Avg. 2.02%). The montmorillonite content has slightly increased with depth and highest at 3180 ft.

4.2 Lower unit A

The lower unit A has approximately 3980 to 5800 feet, the percentage of mineral compositions are 28.38 to 62.11% of quartz (Avg. 41.62%), 12.94 to 37.65% of kaolinite (Avg. 23.80%), 6.67 to 17.66% of illite (Avg. 11.53%), 0.48 to 1.92% of chlorite (Avg. 1.33%), 0.00 to 33.09% of calcite (Avg. 8.05%), 3.91 to 12.73% of feldspar (Avg. 9.04%), and 2.75 to 8.12% of montmorillonite (Avg. 9.04%). The montmorillonite content has stable or slightly increased with depth and high value at 4360, 4470, and 4470 feet, respectively.

4.3 Unit B

Unit B has 5800 to 6800 feet approximated depth. The percentage of mineral composition are 7.97 to 41.03% of quartz (Avg. 28.37%), 10.18 to 17.84% of kaolinite (Avg. 13.68%), 8.48 to 16.60% of illite (Avg. 12.31%), 0.46 to 0.68% of chlorite (Avg. 0.56%), 8.70 to 46.57% of calcite (Avg. 34.67%), 4.22 to 6.31% of feldspar (Avg. 5.12%), and 2.99 to 8.90% of montmorillonite (Avg. 5.30%). The montmorillonite content has slightly increased with depth and highest value at 6700 feet.

4.4 Unit C

Unit C has approximately 6800 to 9200 feet. The percentage of mineral composition are 29.17 to 72.38% of quartz (Avg. 54.96%), 10.18 to 33.20% of kaolinite (Avg. 17.70%), 6.82 to 16.35% of illite (Avg. 11.84%), 0.90 to 1.99% of chlorite (Avg. 1.44%), 0.00 to 1.71% of calcite (Avg. 0.53%), 5.33 to 13.16% of feldspar (Avg. 7.99%), and 2.70 to 8.10% of montmorillonite (Avg. 5.54%). The montmorillonite content has slightly decreased with depth and the high value at 7110 and 8110 feet, respectively.

4.5 Relation of clay mineral and shale swelling in FA-SS- 35-04 well

The overall Mae Sod formation from FA-SS-35-04 well has approximately 2600 to 9200 feet of depth. From the result of data of 39 sample, the percentage of mineral composition is 17.97 to 82.20% of quartz (Avg. 51.26%), 5.05 to 37.65% of kaolinite (Avg. 17.68%.), 1.75 to 17.66% of illite (Avg. 9.97%), 0.00 to 1.99% of chlorite (Avg. 0.99%), 0.00 to 46.57% of calcite (Avg. 6.83%), 3.91 to 17.49% of feldspar (Avg. 9.27%), and 0.59 to 8.90 of montmorillonite (Avg. 3.99%). The data reveals that the most of quantity of clay mineral composition of shale drill cuttings from FA-SS-35-04 well are kaolinite, illite, montmorillonite, and chlorite. These clay mineral compositions are slightly increased with depth, especially the montmorillonite affected to the shale swelling zone. Moreover, the average montmorillonite content represents 2.02 % of upper unit A, 4.96% of lower unit A, 5.30% of unit B, 5.54% of unit C. Therefore, the montmorillonite trend is increased with depth according to upper unit A, lower unite A, unit B, and unit C, respectively whereas drilling through these depths needs to be more careful.

Table 1. Mineral compositions of Mae Sod formation from FA-SS-35-04 well in San Sai oil field.

Sample no.	formation	Unit	depth(ft.)	Mineral compositions (%)							Average value
				Q	K	Il	Ch	Ca	Feld	Mon	
1	Mae Sod	upper unit A	2680	63.85	17.04	6.93	0.95	0.00	8.44	2.42	Q = 63.99%
2			2790	66.30	16.24	6.89	0.91	0.00	7.62	2.05	K = 14.52%
3			2820	82.20	5.05	1.75	0.16	0.02	10.26	0.59	Il = 7.04%
4			2950	70.78	12.78	5.19	0.67	0.01	8.77	1.69	Ch = 0.63%
5			2980	53.94	19.57	10.38	0.78	0.00	12.30	3.03	Ca = 0.02%
6			3000	68.74	9.61	6.40	0.36	0.00	13.91	0.98	Feld = 11.75%
7			3030	70.76	8.32	4.77	0.23	0.00	14.96	0.96	Mon = 2.02%
8			3080	47.38	20.76	11.08	0.93	0.00	17.49	2.36	
9			3150	75.22	6.53	6.26	0.00	0.00	9.48	2.51	
10			3180	37.41	31.27	13.05	1.58	0.00	12.52	4.16	
11			3220	77.44	8.19	3.56	0.30	0.21	9.45	0.85	
12			3240	68.48	10.68	5.54	0.55	0.05	13.50	1.20	
13			3270	64.54	12.76	7.26	0.49	0.02	13.31	1.62	
14			3930	53.06	21.22	9.83	1.02	0.00	11.54	3.34	
15			3980	59.75	17.77	6.66	0.59	0.00	12.72	2.51	
16		Lower unit A	4020	62.11	16.46	6.67	0.99	0.00	11.03	2.75	Q =41.62%
17			4110	46.67	26.47	8.63	1.24	0.00	12.73	4.25	K = 23.80%
18			4140	46.67	26.47	8.63	1.24	0.00	12.73	4.25	Il = 11.53%
19			4170	51.01	24.33	8.78	1.43	0.00	9.82	4.62	Ch = 1.33%
20			4360	41.72	31.78	10.52	1.85	0.00	8.26	5.86	Ca = 8.05%
21			4470	28.38	37.65	14.16	1.58	0.00	10.11	8.12	Feld = 9.04%
22			4500	29.43	31.80	14.35	1.92	5.16	10.16	7.17	Mon = 4.96%
23			4640	43.79	21.56	10.98	1.46	10.90	6.48	4.84	
24			4740	36.14	16.23	17.66	1.75	19.51	3.91	4.79	
25			4840	39.21	16.07	14.10	0.68	19.88	5.74	4.31	
26			4940	32.67	12.94	12.40	0.48	33.09	4.77	3.65	
27		Unit B	5830	19.93	15.73	10.51	0.56	45.36	4.91	2.99	Q = 28.37%, K = 13.68%
28			6160	17.97	11.93	14.13	0.46	45.44	4.72	5.36	Il = 12.31%, Ch = 0.56%
29			6280	23.36	12.52	8.48	0.68	46.57	4.22	4.17	Ch = 0.56%, Ca = 8.05%
30			6450	39.58	10.36	11.84	0.47	27.27	5.42	5.06	Feld = 5.12%, Mon = 5.30%
31			6700	41.03	17.84	16.60	0.63	8.70	6.31	8.90	
32		Unit C	7110	29.17	33.20	14.60	1.35	0.42	13.16	8.10	Q = 54.96%
33			7300	72.38	10.18	7.01	0.90	0.00	5.33	4.20	K = 17.70%
34			8110	47.21	19.04	14.63	1.41	0.10	9.54	8.06	Il = 11.84%
35			8120	48.17	18.86	16.35	1.30	0.46	8.00	6.87	Ch = 1.44%
36			8680	58.36	15.40	11.97	1.78	0.79	6.72	4.98	Ca = 0.53%
37			8730	53.43	15.83	12.02	1.76	1.71	9.60	5.66	Feld = 7.99%
38			8830	72.31	10.56	6.82	1.02	0.77	5.81	2.70	Mon = 5.54%
39			9150	58.62	18.53	11.31	1.99	0.00	5.77	3.78	

Remarks: Q = Quartz, K = Kaolinite, Il = Illite, Ch = Chlorite, Ca = Calcite, Feld = Feldspar, Mon = montmorillonite, and ft =feet.

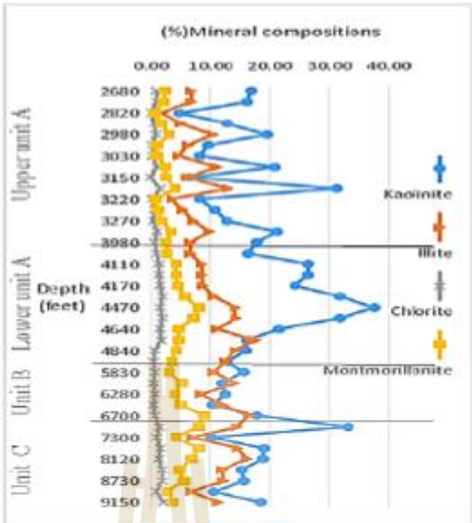

Figure 4. Clay mineral composition of FA-SS-35-04 well with depth.

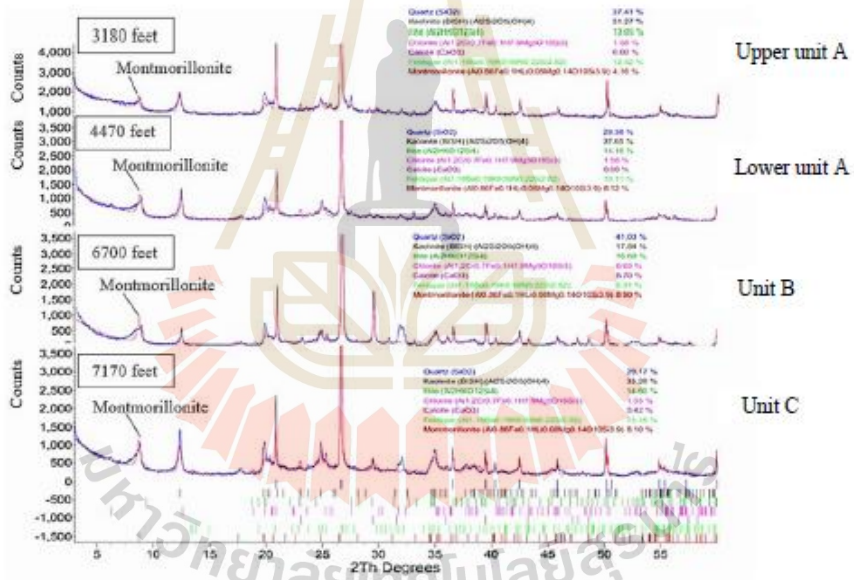

Figure 5. The results of X-ray diffraction for the highest of montmorillonite from upper unit A (3180 feet), lower unit A (4470 feet), unit B (6700 feet), unit C (7170 feet) respectively.

5. Conclusions

Thirty-nine drill cuttings of Mae Sod formation from FA-SS-35-04 well were analyzed by X-ray diffraction (XRD) method, and it mainly represented 4 types of clay mineral including kaolinite (5.05 to 37.65%), illite (1.75 to 17.66%), chlorite (0.00 to 1.99%), and montmorillonite (0.59 to 8.9%). The montmorillonite is a significant impact on shale swelling, which it represents in all units of Mae Sod formation increasing with depth. According to this result, the lower zone of Mae Sod formation could be aware of shale swelling. This indicates that the shale layer of unit C tends to be swollen than unit B, lower unit A, and upper unit A, respectively. These data can be used as a prerequisite for planning drilling through the Mae Sod formation shale. Therefore, according to the result of this study provides depth could be aware of shale swelling especially in lower unit A (at 4360, 4470, 4500 feet), unit B (at 6160, 6450, 6700 feet), and unit C (at 7170, 8110, 8120, 8680 feet).

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BIOGRAPHY

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