การประยุกต์วิธีการสำรวจความต้านทานไฟฟ้าจำเพาะร่วมกับข้อมูลแม่เหล็กไฟฟ้าโดเมนของเวลาเพื่อสร้างแบบจำลองทางอุทกธรณีวิทยาเชิงมโนทัศน์ในจังหวัดกำแพงเพชร

นายเนติ ควรเอี่ยม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2557

APPLICATION OF ELECTRICAL RESISTIVITY METHOD COMBINED WITH TIME DOMAIN ELE CTROMAGNETIC DATA FOR CONCEPTUAL HYDROGEOLOGICAL MODELING IN CHANGWAT KAMPHAENGPHET

Mr. Neti Kuaneiam

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Geology
Department of Geology
Faculty of Science
Chulalongkorn University
Academic Year 2014

Thesis Title	APPLICATION OF ELECTRICAL RESISTIVITY METHOD COMBINED WITH TIME DOMAIN ELECTROMAGNETIC DATA FOR CONCEPTUAL HYDROGEOLOGICAL MODELING IN CHANGWAT KAMPHAENGPHET
By	Mr. Neti Kuaneiam
Field of Study	Geology
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เนติ ควรเอี่ยม : การประยุกต์วิธีการสำรวจความต้านทานไฟฟ้าจำเพาะร่วมกับข้อมูลแม่เหล็กไฟฟ้าโดเมนของเวลาเพื่อสร้างแบบจำลองทางอุทกธรณีวิทยาเชิงมโนทัศน์ในจังหวัดกำแพงเพชร (APPLICATION OF ELECTRICAL RESISTIVITY METHOD COMBINED WITH TIME DOMAIN ELECTROMAGNETIC DATA FOR CONCEPTUAL HYDROGEOLOGICAL MODELING IN CHANGWAT KAMPHAENGPHET) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. ฐานบ ธิติมากร, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร. ศรีเลิศ โชติพันธรัตน์, 132 หน้า.

จังหวัดกำแพงเพชรตั้งอยู่ในพื้นที่แอ่งเจ้าพระยาตอนบนของประเทศไทยซึ่งมีการขยายตัวทางด้านเกษตรกรรมต่อเนื่องอย่างรวดเร็ว การอาศัยแหล่งน้ำผิวดินเพียงอย่างเดียวทำให้เกิดภาวะขาดแคลนน้ำได้ การนำแหล่งน้ำบาดาลมาใช้เพื่อตอบสนองต่อความต้องการใช้น้ำที่เพิ่มขึ้นจึงเป็นทางเลือกหนึ่งที่จะช่วยบรรเทาและแก้ไขภาวะขาดแคลนน้ำในช่วงฤดูแล้งได้อย่างมีประสิทธิภาพ โดยเฉพาะอย่างยิ่งในพื้นที่ศึกษาที่น้ำบาดาลถูกกับเก็บอยู่หินแข็งซึ่งทำการสำรวจน้ำบาดาลได้ยาก วิธีที่นิยมนำมาสำรวจน้ำบาดาลได้แก่เทคนิคการสำรวจวัดความต้านทานไฟฟ้าจำเพาะ การสำรวจวัดความต้านทานไฟฟ้าแบบหยั่งลึกจะขาดความต่อเนื่องของข้อมูล ในภายหลังจึงได้มีการใช้ระบบการอ่านแบบหลายขั้ว ทำให้ในงานสำรวจแหล่งน้ำบาดาลสามารถเห็นรายละเอียดได้ดียิ่งขึ้น โดยเฉพาะอย่างยิ่งการนำข้อมูลการบินสำรวจธรณีฟิสิกส์วัดค่าสนามแม่เหล็กไฟฟ้าผนวกกับข้อมูลการสำรวจวัดค่าความต้านทานไฟฟ้ากระแสตรง จะช่วยให้วิเคราะห์ลักษณะของชั้นน้ำบาดาลและตำแหน่งเจาะบ่อได้แม่นยำยิ่งขึ้น

โดยบริเวณส่วนใหญ่ของพื้นที่ศึกษาปกคลุมด้วยตะกอนหินผุ และบางบริเวณแปรสภาพเป็นศิลาแลง ซึ่งรองรับด้วยหินฟิลไลต์ยุคไซลูเรียน – ดีโวเนียนในระดับตื้น ซึ่งมีค่าความต้านทานไฟฟ้าสูงมากกว่า 200 โอห์มเมตรขึ้นไป โดยในพื้นที่ศึกษาพบบริเวณที่ง่ายต่อการผุพังและสึกกร่อนในชั้นหินให้น้ำยุคไซลูเรียน – ดีโวเนียน ได้แก่บริเวณหินผุ หรือ/และรอยแตก หรือ/และรอยเลื่อนขนาดใหญ่ของหินฟิลไลต์ซึ่งวางตัวในแนวเหนือ-ใต้ของพื้นที่ศึกษา ผลการสำรวจทางธรณีฟิสิกส์ของบริเวณดังกล่าวแสดงค่าความต้านทานไฟฟ้าต่ำอยู่ในช่วง 10 – 50 โอห์มเมตร ซึ่งเป็นชั้นน้ำบาดาลหลักในพื้นที่และบริเวณที่มีศักยภาพทางน้ำบาดาลสูงสามารถเจาะพัฒนาบ่อน้ำบาดาลได้ โดยทิศทางการไหลหลักของน้ำบาดาลจะอยู่ในแนวภูเขาสูงด้านตะวันตกลงสู่แอ่งตะกอนด้านทิศตะวันออก และทิศทางการไหลของน้ำบาดาลในชั้นหินแข็งจะถูกควบคุมโดยรอยแตกและรอยเลื่อนภายในหิน

ภาควิชา	ธรณีวิทยา	ลายมือชื่อนิสิต	....
สาขาวิชา	ธรณีวิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
ปีการศึกษา	2557	ลายมือชื่อ อ.ที่ปรึกษาร่วม	....

5472185023 : MAJOR GEOLOGY
KEYWORDS: GROUNDWATER / KAMPHAENGPHET / VES / TEM / RESISTIVITY

NETI KUANEIAM: APPLICATION OF ELECTRICAL RESISTIVITY METHOD COMBINED WITH TIME DOMAIN ELECTROMAGNETIC DATA FOR CONCEPTUAL HYDROGEOLOGICAL MODELING IN CHANGWAT KAMPHAENGPHET. ADVISOR: ASST. PROF. THANOP THITIMAKORN, Ph.D., CO-ADVISOR: ASST. PROF. SRILERT CHOTPANTARAT, Ph.D., 132 pp.

Kamphaengphet is a part of upper Chao Phraya basin of Thailand. The rapid growth of agriculture results in significantly growing water demand. Reliance on surface water only causes water shortage. Groundwater resources are great alternatives to satisfy such a growing water demand, which solves the water shortage in dry season efficiency. Especially in the study area has groundwater stored in consolidated rocks that are difficult investigated. The popular methodology for groundwater survey is electrical geophysical technique. The vertical electrical sounding technique lacks data continuity. Later, the exploration has been relying on the multi–electrode system, resulting in accurate surveys and continuity resistivity data. Combining airborne time – domain electromagnetic data with electrical resistivity data will help investigate aquifers characteristics and pinpoint drilling well location accurately.

Most of the study area overlain by residual soils and some area has already been changed to laterite that are underlain by shallow Silurian – Devonian phyllite which has resistivity higher than 200 ohm-meters. The study area shows significant weak zones in Silurian - Devonian rocks aquifers that are weathered phyllite. The fractures or fault zone is aligned in northern-southern directions. The weak zone has resistivity range from 10 to 50 ohm-meters which is the primary aquifer of the study area. This zone has high groundwater potential and groundwater well can be developed. Primary groundwater regional flow is from the northern high mountain to southern basin direction. The flow pattern in this consolidated aquifers is controlled by fractures or faults in rock formation.

Department:	Geology	Student's Signature	....
Field of Study:	Geology	Advisor's Signature	....
Academic Year:	2014	Co-Advisor's Signature	....

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to Assistant Professor Dr. Thanop Thitimakorn, thesis advisor, Assistant Professor Dr. Srilert Chotpantarat, co-advisor for their inestimable advice, valuable suggestion, who introduced me to the methodology of research and provided me the possibility to complete this thesis. In addition, a thank you to Professor Dr. Montri Choowong, Assistant Professor Dr. Pitsanupong Kanjanapayont, Dr. Vichai Chutakositkanon, and Assistant Professor Winit Youngme for valuable advices that greatly improved this research.

In addition, I honestly appreciate the department of groundwater resources (DGR) for provide valuable information and priceless geophysical data support. Furthermore, this research was supported by GMT corporation co., ltd., especially, I express my deepest thank to Mr. Wicharn Arunsrisangchai for provision of financial support, providing necessary guidance project implementation and arranged all facilities to make work easier. I choose this moment to sincerely acknowledge his contribution gratefully.

Moreover, this thesis would not be complete without my close friend “Mr.Vacharayu Teyateeti” for advice and gave suggestion about thesis grammar and improve my thesis idiom that splendid enhance this thesis report. A special thank goes to my friend, Kesama Rattanopas, Puttiporn Chatpaisarn, Paratchata Batsomboon, Sarawut Lapngamchana, and other, who encourage me and gave valuable suggestion.

Finally, this thesis could not have been accomplished without the support and assist of my family and my best teacher Ajarn Pu who always put up so much effort to the completion of this thesis.

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CHAPTER I
INTRODUCTION

1.1 Rational

Changwat Kamphaengphet is located in the upper Chao Phraya basin of Thailand. The rapid growth of agriculture and industries results in significantly growing water demand, especially from agriculture section with a great number of off-season rice, cassava, and sugar cane farms. Reliance on surface water only without groundwater caused water shortage and drought risk as 2548 B.E. Water shortage attributable to climate variability in various localities damaged wide area of community and farmland. Groundwater resources are great alternatives to satisfy growing water demand, which solves the water shortage in dry season efficiency.

Changwat Kamphaengphet is situated in the lower Ping River basin and displays as alluvial terrace with elevation 60 – 140 meters above mean sea level. Potential surface water source is from the Ping River (DMR, 2550). The groundwater in study area is divided into 2 types according to reservoir characteristics consisting of unconsolidated-rocks aquifers storing groundwater in sediment, which is the primary groundwater aquifer in the study area, and consolidated-rock aquifers storing groundwater in rock structures such as holes, fractures, or faults, producing low water yield except large fault or large cavity zone.

Aquifer characteristic expansion surveys have been studied for a long time based on geophysical knowledge. The popular methodology is geophysical survey to determine the specific electrical resistance of aquifer by using direct current which is called “geophysical direct current resistivity survey” (DC resistivity survey). Aquifer resistance depends on porosity, water resistance, type and characteristic of sediment, and electrical conductivity of clay minerals.

The geophysical DC resistivity survey uses vertical electrical survey (VES) technique exploring and collecting single point data, which takes a long exploration time and lacks data continuity. Later, the exploration has been relying on the multi – electrode system that can use Schlumberger, Dipole – Dipole, or other array systems, resulting in accurate groundwater surveys and continuity resistivity data. Additionally, the method can help discover consolidated-rock aquifers containing groundwater in fractures, faults, holes, or shearing zone which are hard to explore and have a high risk of failure by relying solely on VES. 2D imaging multi - electrode resistivity survey technique can estimate aquifers depth and position more accurate and faster than typical vertical electrical sounding (VES) 1D imaging technique. The more continual data, the better interpretation.

However, DC resistivity survey has some limitation. For example, the survey in regional scale will take a long time, its maximum investigation depth is approximately 100 - 200 meters (depending on rock/soil characteristic, rock/soil type, wire length, and the current strength), and inaccessible area such as deep forest or overgrown areas. In addition, only single resistance data from resistivity survey cannot estimate soil depth and characteristic accurately. The interpretation requires a combination of lithological logs, wire-line logs and other data for more reliable. Application of several geophysical survey techniques in combination with DC resistivity survey provides the better and more dependable results. Nowadays, the explorations apply several techniques from various researches, including airborne time-domain and frequency-domain electromagnetic to study hydrogeology and aquifers.

Kurt l.S. and Auken E. (2004) developed groundwater survey technique which applied airborne Time-domain electromagnetic called SkyTEM by using helicopter for exploration in several areas within Denmark. The main cause of time – domain electromagnetic method (TEM) development was that frequency – domain electromagnetic method (FEM) had high sensibility for mineral deposits (low electric resistance) in host rock areas (high electric resistance > 100,000 Ωm.), which are general geological mineral deposits in North America, leading to ambiguous results. Moreover, for example, many areas of Australia overlain by thick bed Rhyolites (> 100 m.) have low electric resistance, cause FEM technique therefore cannot easily penetrated this layer. This drives the development of TEM techniques in Australia despite the technical difficulty from features and characteristics of electronic device in the past. In 2003 A.D., Flemming J. and Auken E. applied TEM technique for survey old river channel in Denmark for the first time. It is found that river channels are distributed throughout Denmark. This aquifer is the primary water source for all domestic consumption in the country without reliance on surface water. The survey results are satisfactory.

Time – domain electromagnetic method (TEM) has been become more popular in ground water survey and geological mapping section. The main objective of time – domain electromagnetic method application is the requirements regarding the data accuracy having high spatial density. These include tools and equipment, processing, and interpretation accuracy for precise geological and hydrogeological interpretation. There are many cases that researchers face the problem that aquifers exploration and mapping alone is not sufficient for interpretation, which calls for other factors such as geological structures, aquifers and soil layer size, volume variables, including covered surface characteristics of geophysical in study area.

At the present time, there are many researches that compared results and equipment performances of time – domain and frequency – domain methods. For example, Munday T. and et al.(2007), tested these techniques in Murray River basin in the south of Australia. Frequency – domain employed RESOLVE frequency domain helicopter electromagnetic (FDHEM) system, and Time – domain used SkyTEM time domain helicopter electromagnetic survey (TDHEM). It is found that both systems can classify and investigate salt water intrusion near estuary. Frequency – domain showed a slightly better result in shallow zone near the surface, but in the thick clay layer or deep zone, time domain clearly gave more accurate result than Frequency – domain which cannot penetrate thick conductive layers.

Although airborne time – domain electromagnetic method can penetrate deeper, faster, wider, and clearly classify clay-sand sediments, but it had some limitation about hard to classify high electric resistance rock/soil layer and provided less details when compared with ground survey. The method is easily affected by building, household, and electricity post, causing error interpretation.

Therefore, application of airborne time – domain electromagnetic method (TEM) in combination with DC resistivity survey, consisting of vertical electrical sounding (VES), multi – electrode system, and lithological and wire-line logging, will analyze aquifers characteristics, aquifers expansion, aquifers depth, and drilling wells location accurately.

1.2 Objective

In this study area, characteristic of aquifers and groundwater potential areas are main objectives. The difference of rock/soil types and variety kind of structures such as fracture, fault, hole or shear zone related to geological setting are also concerned. This research objective is to present and interpret the potential aquifers details in the study area within Kamphaengphet province. The main objectives of this study are as follows.

1. To analyze the extension, thickness and hydrogeological properties of aquifers in the study area.
2. To examine groundwater potential zone in the study area.
3. To create the conceptual model of the study area.

1.3 Scope of work

This thesis focuses on the hydrogeological unit or aquifers classification and interpretation of both unconsolidated and consolidated rock in the study area within Khlongmaelai, Amphoemuang , Kamphaengphet province, which is approximately 750 Rai. or 1.2 square kilometers having electromagnetic lineaments anomalies.

1.4 Assumption

Upon reviewing the “Groundwater mapping within Kamphaengphet province” at scale 1:100,000 (DGR, 2001), that represented 2 hydrogeological units consist of unconsolidated rock is old terrace deposits aquifers underlain by consolidated rocks is Silurian-Devonian Metamorphic aquifers. The unconsolidated rocks groundwater potentials are stored in sand and gravel sediment with well sorted, represented in high resistivity value approximately 100 – 160 ohm.meters. The consolidated rocks groundwater potentials are stored in cavitys, fractures, or faults represented lineaments anomalies in low resistivity zone of hard rock.

1.5 Expected output

The major expectation of this thesis is to understand the characteristics of aquifers, and groundwater potential area. Expected results are as follows:

1. Aquifer characteristics and groundwater potential area.
2. Groundwater potential zone
3. Conceptual model

CHAPTER II
LITERATURE REVIEW

2.1 General information in regional scale

According to "Classification for geological management and resources, Kamphaengphet" (DMR, 2012), Kamphaengphet is the upper central province in 15° 51' -16° 54' Latitude and 90° - 100° 3' Longitude with 8,607.5 square kilometers (5,379,687.5 Rai). Its topography is complex mountains areas with slopes down toward the east in the west, hilly plain in the central and north, and terrace deposited Ping river basin in the east and south, with is 43– 107 meters above mean sea level.

2.1.1 Geology and Geological stratigraphy units

According to "Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin" at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet province (DGR, 2010) and "Classification for Management The Geology and Mineral Resources, Kamphangphet province" (DMR, 2012), the chrono – lithological units are divided into 14 geological units, including igneous rocks, sedimentary rocks, metamorphic rocks, and unconsolidated sediments such as clay, sand, and gravel, which are arranged in ascending order (oldest-youngest) from Precambrian rocks to Quaternary unconsolidated sediments (Figure 2.1.1-1), the information is as follows :

(1) Igneous rocks - consists of 2 units, including granitic and volcanic rocks

a. **Granitic rocks (Gr)** – their majority appear in highly steeps - lower mountain ranges, which particularly occurs as weathered rock debris rolling hills within upper part on the west of Kosamphi Nakhon, Mueng Kamphaengphet, and Khlong Lan districts, composing of various kinds of Triassic granitic rocks (Trgr) including quartz-biotite granite, fine-grained hornblende granite, and light green coarse-grained grano-diorite.

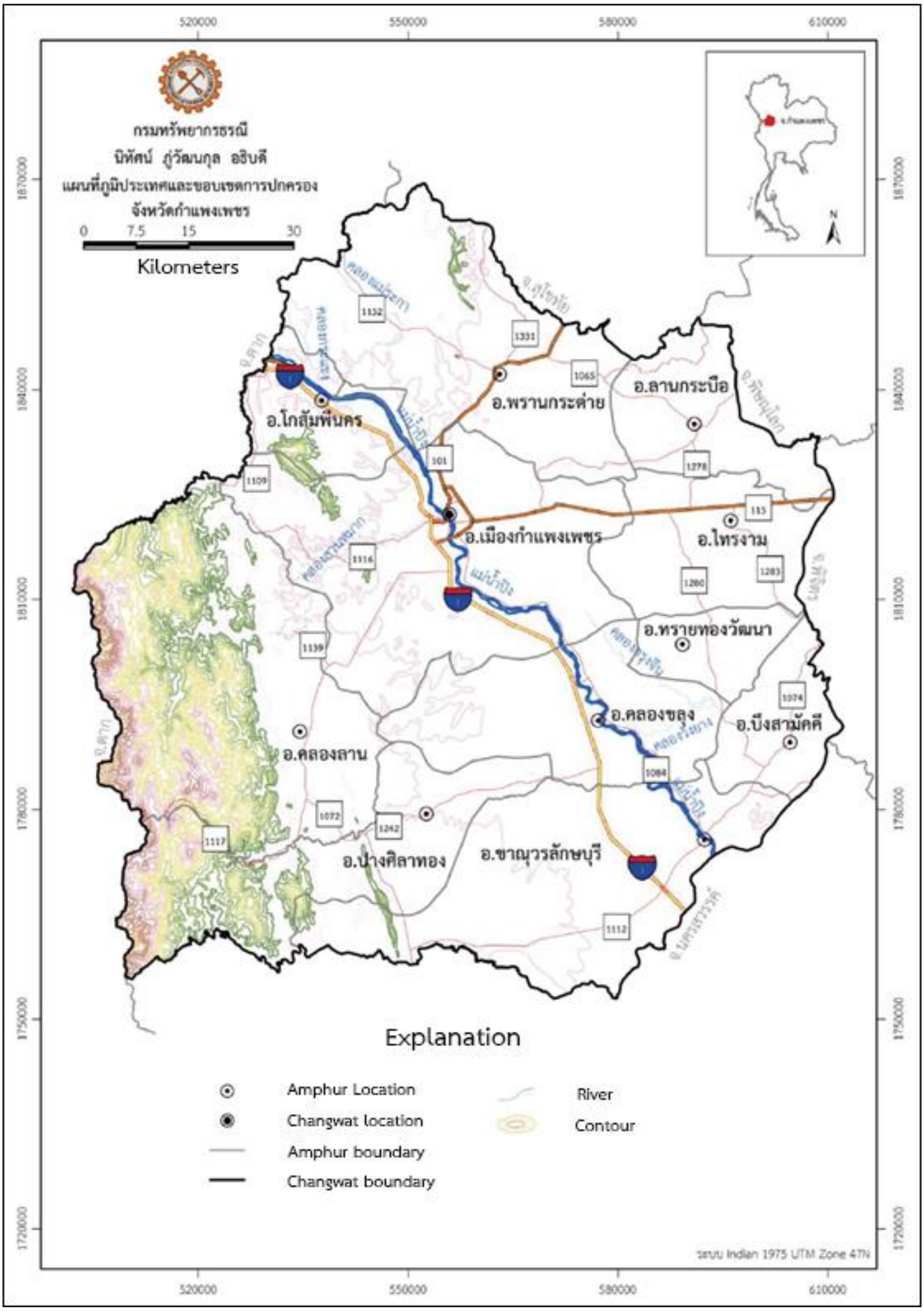


Figure 2.1-1. Topography map and administrative district of Kamphaengphet (refers to “Classification for Management The Geology and Mineral Resources, Kamphangphet”) (DMR, 2012)

a. **Volcanic rocks (Vc)** – appear in the central part of Kamphaengphet provinces within Kosamphinakhon, and Phran Kratai districts, composing of various kind of Permian - Triassic volcanic rocks, including reddish purple – greyish purple rhyolitic tuff, Porphyritic rhyolite, and light pink fine-grained rhyolite.

(2) **Sedimentary and Metamorphic rocks** –

a. **Precambrian rocks (P€)** – appear in the south-western part of Kamphaengphet province within Klong Lan districts, composing foliated dark gray fine-grained mica schist, greenish gray schistoscity Cal-Silicate rocks, orthorgneiss which usually occurs lens structure consisting of quartz, feldspar, and foliated mica.

b. **Cambrian rock (€) –** Their majority appear in the north-western mountain ranges within parts of Muang Kamphaengphet district, Kamphaengphet province, composing of light gray massive quartzite, dark gray mica-schist interbedded with quartz-schist, white and light yellow schist, quartz-mica-schist, and phyllite.

c. **Silurian–Devonian rocks (Sd)** - appear in western part of Kamphaengphet province within KlongLan and Mueng Kamphaengphet districts, composing of greenish gray, very fine-grained phyletic shale with granoblastic texture, showing fracture cleavage and particularly showing silicification, metamorphosed light gray arkosic sandstone consisting mostly of cracked quartz affected by faulting, metamorphosed light gray feldsparthic sandstone with granoblastic texture, consisting of quartz, feldspar, showing slickenside texture, and light gray fine-grained arkosic sandstone, interbedded with white mudstone consisting of feldsparthic clay.

d. **Permian – Carboniferous rocks (PC)** – appear in mountain ranges or monadnock within the south-western part of Kosampeenakorn district, Kamphaengphet province. These rocks comprise brownish gray quartzite, siltstone, and phyletic tuff.

e. **Triassic Rocks (Trpt)** – appear in mountain ranges or monadnock areas within south-west part of Kosampeenakorn district, Kamphaengphet province. The rocks are composed of massive bed brown - reddish brown coarse-grained sandstone or conglomerate interbedded with reddish brown mudstone

f. **Jurassic rocks (J)** – appear in mountain ranges or hills within the central part of Klong Lan district, Kamphaengphet province. The rocks are composed of brown-reddish brown sandstone or/and siltstone alternate with reddish brown shale, and conglomerate with coarsening upward sequence, sub rounded - rounded poor sorting. The rocks consist of quartz, sandstone, feldspar, and rhyolite grained, and light gray arkosic sandstone with medium grained, sub angular – rounded, well sorting and are comprised of quartz, feldspar cemented with iron, silica, and calcium oxide. Locally shear zone areas are discovered phyletic conglomerate.

(3) **Quaternary sediment** – is composed of unconsolidated sediments consisting of 5 units as colluvium deposits, old and younger terrace deposits, alluvial fan deposits, and recent alluvial deposits. Details are follows :

a. **Colluvial deposits (Qc)** – appear at foothills on the basin boundary or in the west of Kamphaengphet province within Kosamphinakhon, Khlong Lan, Khlong Khlung and Pang Sila Thong districts. They are in-situ sediments from weathering rocks transported short distance. The sediment components are composed of silt, sand, gravel, and clastics of which the largest size is 12 millimeters, angular roundness and poor – medium sorting. Its regular thickness are approximately 15 – 40 meters.

b. **Old terrace deposits (Qt2)** – appear in the northwestern parts of Kampheangphet province within Phran Kraitai, Kosamphinakhon, and Mueang Kamphaengphet districts. They are from Late Pliocene – Early Pleistocene age. The deposits comprise coarse sand and clayey cobble sediments extensively extending over flat plain basin and underlying the younger terrace deposits.

These deposits are the lowest Quaternary sediment bottom, composing of fine sand – gravel approximately 28 millimeters in size, sub angular – rounded, poor – well sorting. The sediment components are composed mostly of quartz, feldspar, and clastic. These sediments were cemented by iron oxide and changed to laterite. Its thickness are approximately 25-45 meters

c. **Young terrace deposits (Qt1)** - appear in the western and northwestern part of Kamphaengphet province within Phran Kraitai, Kosamphinakhon and Mueang Kamphaengphet districts. The deposits are of Middle Pleistocene age and comprise gravel and sandy clay sediments extensively extending over flat basin plain and underlying the alluvial fan deposits. The sediments comprise fine sand - gravel approximately 22 millimeters in size, sub angular - rounded, poor - well sorting and are mostly composed of quartz, feldspar, and clastics with some mica. Particularly, these sediments were cemented by iron oxide and changed to laterite. Its thickness are approximately 60 - 100 meters.

d. **Old alluvial fan deposits (Qaf2)** – appear in the lower western part of Mueang Kamphaengphet district, toward flat land on the western side of Ping River, in Mueang Kamphaengphet and Khlong Khlung districts. The deposits are of Middle Pleistocene age and comprise fine sand – gravel approximately 15 millimeters in size, sub angular – rounded, poor – well sorting and are mostly composed of quartz, feldspar, and some clastics. Its thickness are approximately 35 – 40 meters.

e. **Younger alluvial fan deposits (Qaf1)** – appear in the eastern of Phran Kratai and Mueang Kamphaengphet districts, reaching down to eastern rim of the project area that bounds Lan Krabue, Sai Ngam, Klong Khlung, Sai Thong Wattana, and Bueng Samakkhi districts. The deposits are from Middle – Late Pleistocene age and comprise fine sand – gravel approximately 15 millimeters in size, angular - sub rounded, poor - well sorting and are mostly composed of quartz, feldspar, and clastics with some mica. Its thickness are approximately 15 – 25 meters.

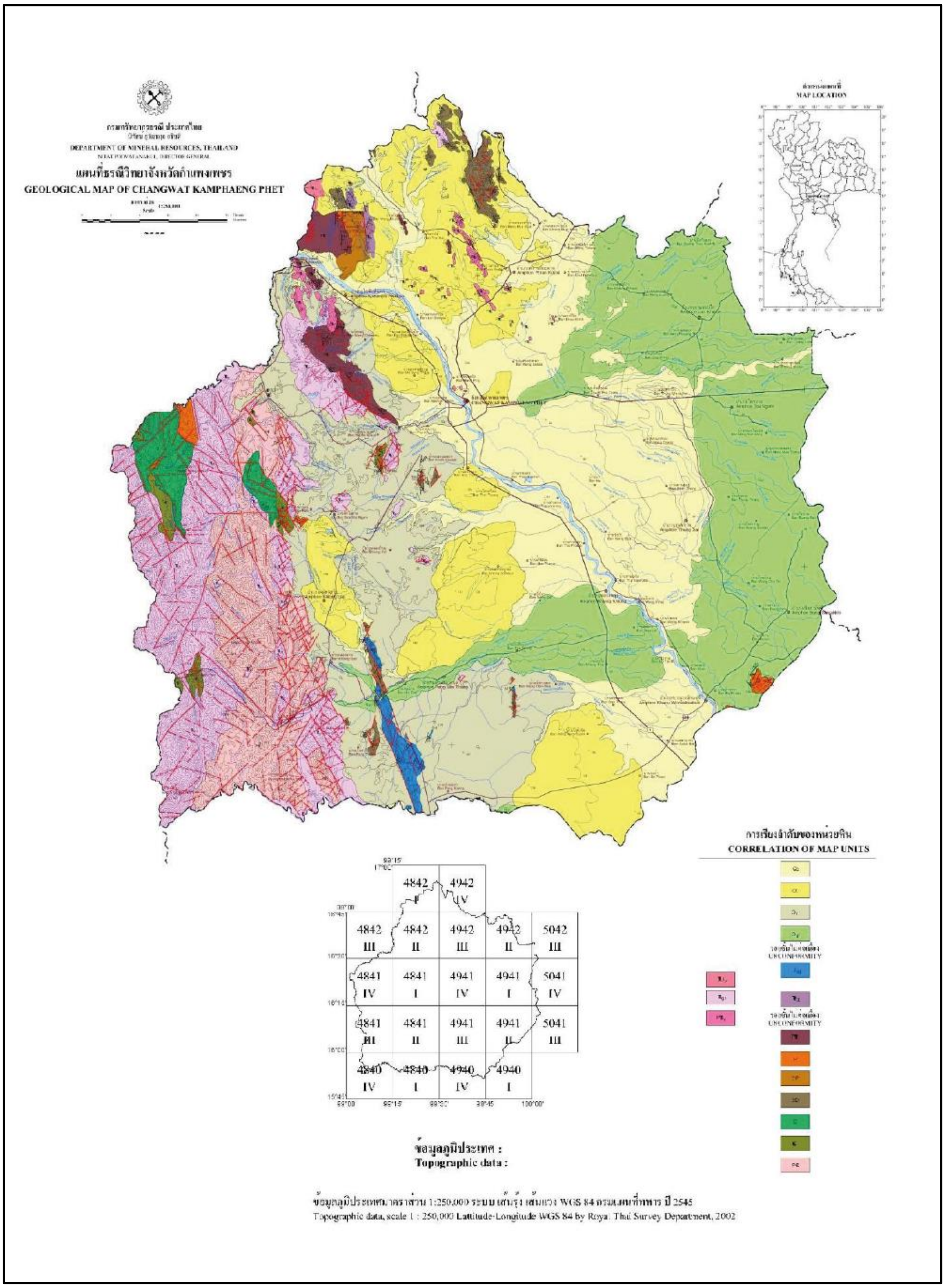
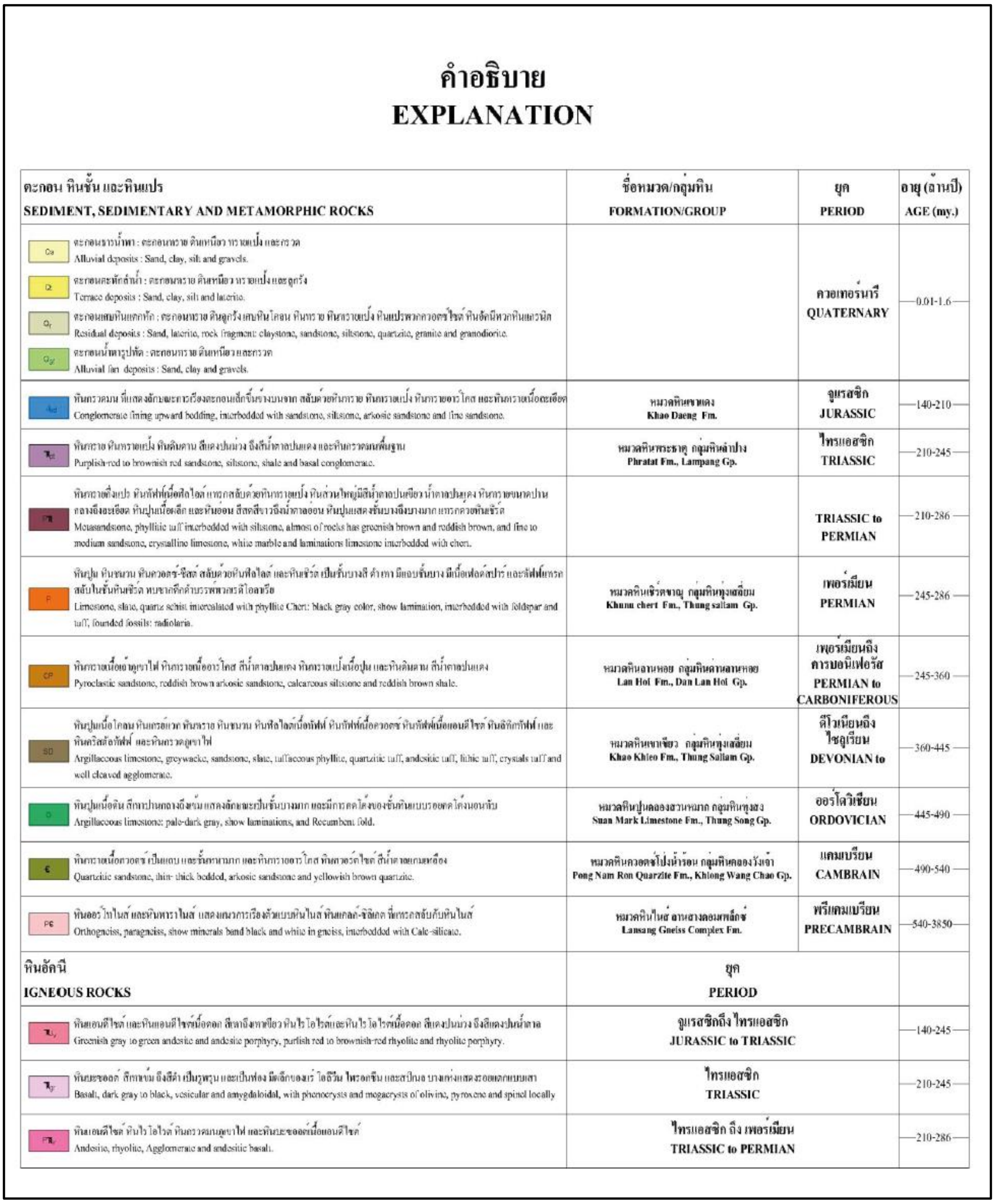


Figure 2.1.1-1. Kamphaengphet Geological map (refers to “Classification for Management Geology and Mineral Resources, Kamphangphet” (DMR, 2012)



คำอธิบาย
EXPLANATION

ตะกอน หินชั้น และหินแปร SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	ชื่อหมวด/กลุ่มหิน FORMATION/GROUP	ยุค PERIOD	อายุ (ล้านปี) AGE (my.)
Qa: Alluvial deposits : Sand, clay, silt and gravels. Qt: Terrace deposits : Sand, clay, silt and laterite. Qr: Residual deposits : Sand, laterite, rock fragment: claystone, sandstone, siltstone, quartzite, granite and granodiorite. Qgf: Alluvial fan deposits : Sand, clay and gravels.		ควอเทอร์นารี QUATERNARY	0.01-1.6
Jkd: Conglomerate fining upward bedding, interbedded with sandstone, siltstone, arkosic sandstone and fine sandstone.	หมวดหินเขาแดง Khao Daeng Fm.	จูแรสซิก JURASSIC	140-210
Trpt: Purplish-red to brownish red sandstone, siltstone, shale and basal conglomerate.	หมวดหินพระธาตุ กลุ่มหินลำปาง Phratat Fm., Lampang Gp.	ไทรแอสซิก TRIASSIC	210-245
PTr: Metasandstone, phyllitic tuff interbedded with siltstone, almost of rocks has greenish brown and reddish brown, and fine to medium sandstone, crystalline limestone, white marble and laminations limestone interbedded with chert.		TRIASSIC to PERMIAN	210-286
P: Limestone, slate, quartz schist intercalated with phyllite Chert: black gray color, show lamination, interbedded with feldspar and tuff, founded fossils: radiolaria.	หมวดหินเชิร์ตขาญ กลุ่มหินทุ่งเสลี่ยม Khum chert Fm., Thung saliam Gp.	เพอร์เมียน PERMIAN	245-286
CP: Pyroclastic sandstone, reddish brown arkosic sandstone, calcareous siltstone and reddish brown shale.	หมวดหินลานหอย กลุ่มหินด่านลานหอย Lan Hoi Fm., Dan Lan Hoi Gp.	เพอร์เมียนถึงคาร์บอนิเฟอรัส PERMIAN to CARBONIFEROUS	245-360
SD: Argillaceous limestone, greywacke, sandstone, slate, tuffaceous phyllite, quartzitic tuff, andesitic tuff, lithic tuff, crystals tuff and well cleaved agglomerate.	หมวดหินเขาเขียว กลุ่มหินทุ่งเสลี่ยม Khao Khieo Fm., Thung Saliam Gp.	ดีโวเนียนถึงไซลูเรียน DEVONIAN to	360-445
O: Argillaceous limestone: pale-dark gray, show laminations, and Recumbent fold.	หมวดหินปูนคลองสวนหมาก กลุ่มหินทุ่งสง Suan Mark Limestone Fm., Thung Song Gp.	ออร์โดวิเชียน ORDOVICIAN	445-490
€: Quartzitic sandstone, thin- thick bedded, arkosic sandstone and yellowish brown quartzite.	หมวดหินควอตซ์โป่งน้ำร้อน กลุ่มหินคลองวังเจ้า Pong Nam Ron Quarzite Fm., Khlong Wang Chao Gp.	แคมเบรียน CAMBRAIN	490-540
P€: Orthogneiss, paragneiss, show minerals band black and white in gneiss, interbedded with Calc-silicate.	หมวดหินไนส์ ลานสางคอมเพล็กซ์ Lansang Gneiss Complex Fm.	พรีแคมเบรียน PRECAMBRAIN	540-3850

หินอัคนี IGNEOUS ROCKS	ยุค PERIOD	
JTrv: Greenish gray to green andesite and andesite porphyry, purlish red to brownish-red rhyolite and rhyolite porphyry.	จูแรสซิกถึง ไทรแอสซิก JURASSIC to TRIASSIC	140-245
Trβ: Basalt, dark gray to black, vesicular and amygdaloidal, with phenocrysts and megacrysts of olivine, pyroxene and spinel locally	ไทรแอสซิก TRIASSIC	210-245
PTrv: Andesite, rhyolite, Agglomerate and andesitic basalt.	ไทรแอสซิก ถึง เพอร์เมียน TRIASSIC to PERMIAN	210-286

Figure 2.1.1-1. Kamphaengphet Geological map (refers to “Classification for management Geology and Mineral Resources, Kamphangphet” (Continue) (DMR, 2012)

2.1.2 Structural geology

According to "the study of geomorphology on the Tertiary basin in Thailand" (Bal & et al, 1992), the crucial structural geology consisting of three major strike-slip fault zones engraved through the Upper Central Plain Basin (Phitsanulok Basin) which is the biggest Tertiary sediments basin of Thailand where Kamphaengphet and the surrounding provinces is situated, including the Phetchabun Fault Zone, Mae Ping Fault Zone, and Uttaradit Fault Zone (or Nam Pat Fault Zone) (Figure 2.1.2-1, and 2.1.2-2). Furthermore, the seismic survey study (Bal & et al, 1992) (Figure 2.1.2-3, 2.1.2-4 and 2.1.2-5) presents that these major fault zones are around carved s the Phitsanulok Basin and its vicinity is in the south, north, and east respectively. In addition, this study reveals normal fault that can be discovered in. Phitsanulok Basin's western boundary as well, which are called the Western Boundary Fault in this study.

In addition, "Advance Airborne Time-Domain Electromagnetic Survey Project" (DGR, 2012) has interpreted LANDSAT satellite imagery analysis on geological structure of Kamphaengphet province and produced LANDSAT lineament imagery map. All geologic structural featuring both small and large size, especially the western and northern part of Kamphaengphet province mountain ranges, are enhanced and emphasized, which presents important structural alignment lineaments in the northwest-southeast and northeast-southwest directions (Figure 2.1.2-6).

(1) **The Phetchabun Faults** – attains about 350 kilometers total length which Khorat and Saraburi Groups cross-cut in. This incision effect is resulted informing of the Phetchabun Basin, and aligning in the north – south direction gradually, which is uninterrupted conjugating fault-line from the Uttaradit Fault that originated from Pak Lay in Laos People's Democratic Republic. Afterwards. Phetchabun fault crosses over to Thailand in the western part of Phu Ruea, which aligns north – south trend through Phetchabun Basin along Pa Sak River and continues to Saraburi province.

(2) **The Mae Ping Faults** – attains about 750 kilometers total length which cut through several rock units from Precambrian to Mesozoic Era. Approximately 100 kilometers of left lateral faults (Sinistral displacement) have been discovered. (Campbell & Nutalaya 1973; Bunopas, 1981; Chantaramee, 1981; Tapponnier &et al., 1986). Nevertheless, they are right lateral fault (Dextral displacement) currently. These faults are combined with several faults including Moei – Uthai Fault or Mae Moei Fault, Wang Chao Fault, and Lan Sang Fault, aligning in the south – eastern direction. Mae Ping Faults originate from Sakiang Fault or Shan Boundary Fault Zone in western Myanmar. It cuts across Thailand and is parallel to Moei River in south-western part of Mae Sariang district of Mae Hong Son province. The Faults passes through Ban Lan Sang, Tak province, Ping River in Kamphaengphet and Nakhonsawan provinces, then proceeds toward Sa Kaeo province and continues into south west Cambodia.

(3) **The Uttaradit Faults** – attains about 250 kilometers total length, aligning in northwest – southeast direction and mainly cuts through The Khorat Group. The Faults begin from Dien Bien Phu Fault Zone in Veitnam, pass through Xaignabouli in Laos, and continue along to Nam Pat River, Khlong Tron, then cross through The Pitsanulok Basin in Uttaradit, Sukothai provinces, and also proceeds into Lan Krabue district of Kampheangphet province. The displacement of faults are right lateral faults (Dextral displacement) which originated during middle Tertiary period, and reversed movement into left lateral fault (Sinitral displacement) during Quaternary period afterwards (Tapponnier & et al, 1986), and attaining long – term slip rate (mm/yr) = 0.04 (Fenton & et al, 1997).

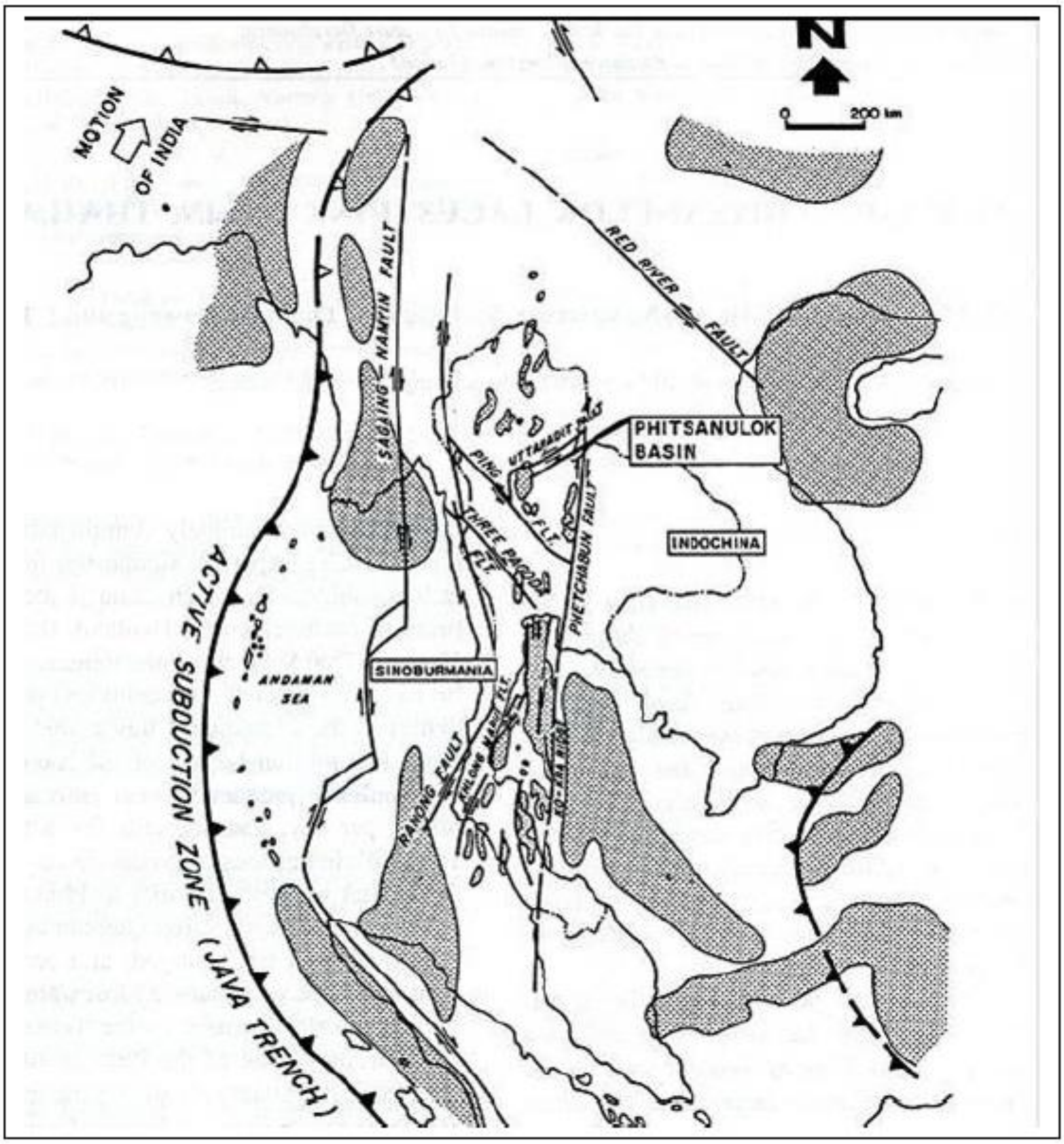


Figure 2.1.2-1. Geotectonic in South-East Asia,

and Tertiary Basin of Thailand (Bal & el al, 1992)

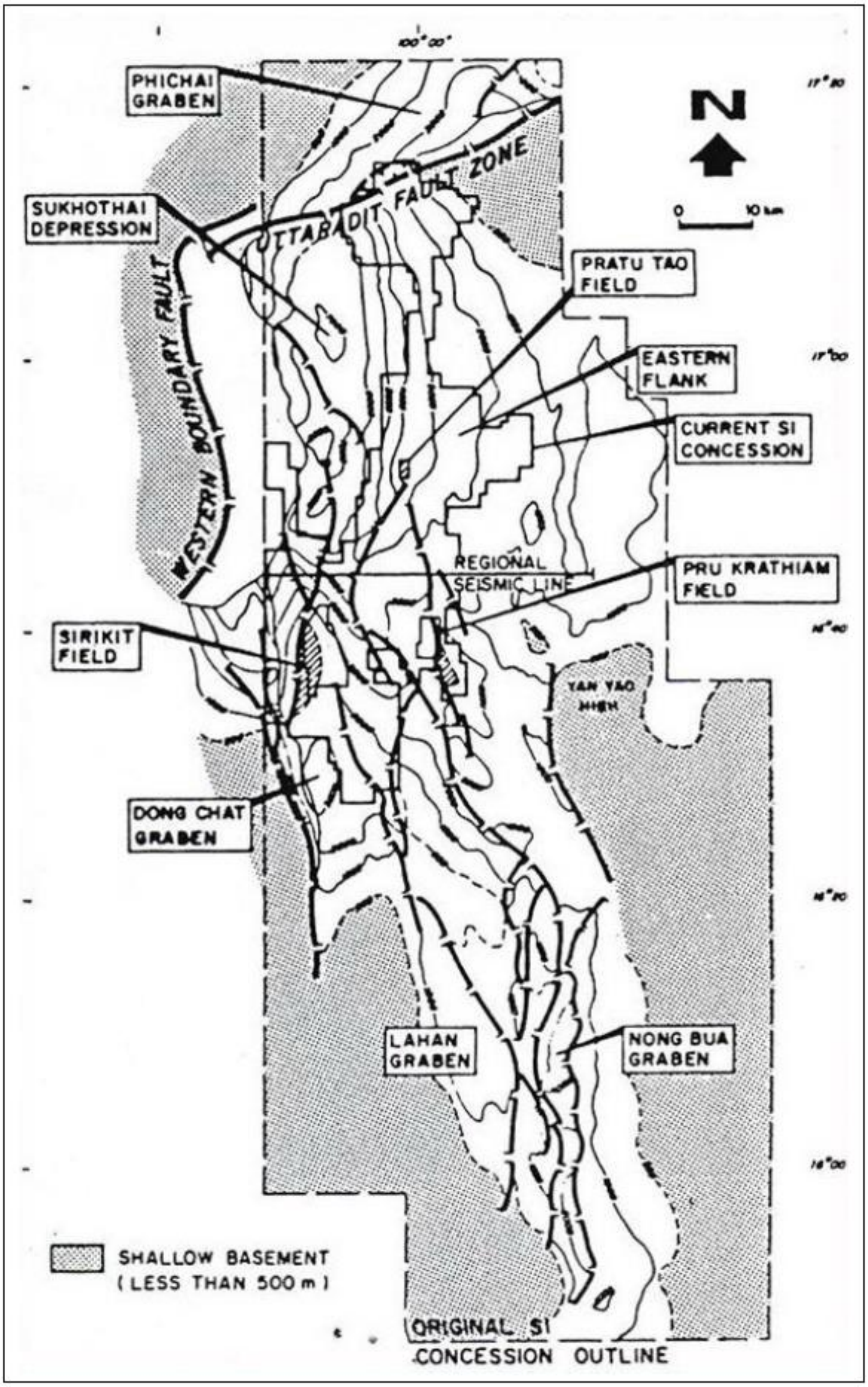


Figure 2.1.2-2. Important geological structures and

East-West seismic survey line of Pitsanulok Basin (Bal & el al, 1992)

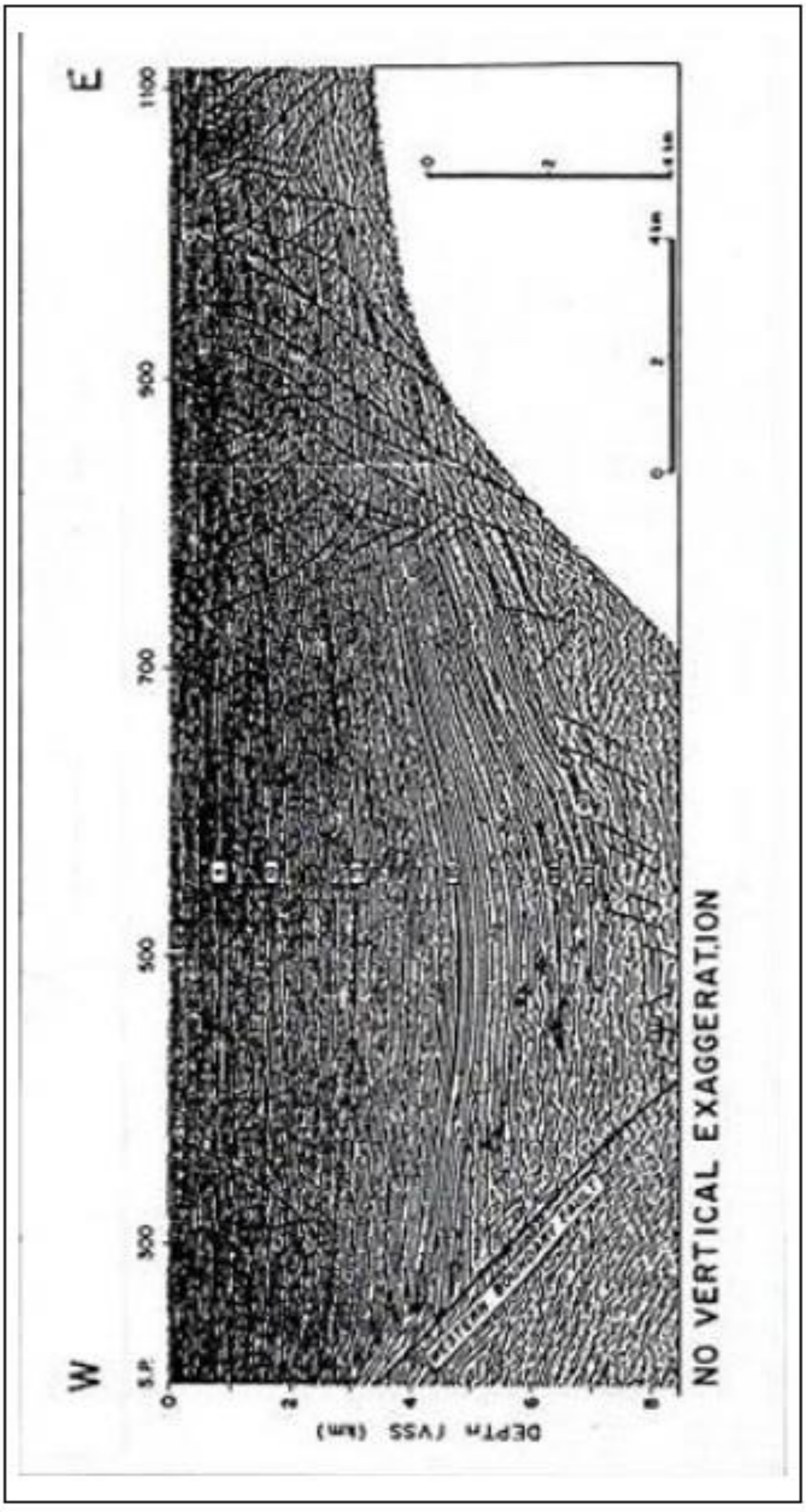


Figure 2.1.2–3. Seismic survey result from primary seismic survey line in East-West direction, that present Pitsanulok Basin geological structure (Bal & el al, 1992)

2.1.3 Hydrogeology and Hydrogeological units

The aquifers are divided into 2 types according to their hydraulic characteristics, which are unconsolidated-rocks are water–bearing unconsolidated materials (such as sand sediment) underground layers, and consolidated-rocks are water – bearing permeable rocks underground layers.

Two important aquifer properties are related to water yield or specific yield porosity, which is the percentage of rock or sediment that consists of voids or openings, which is a measurement of a rock's ability to hold water (Charles C. P. & Diane H. C., 2008) and groundwater storage. Groundwater environments examination indicates that openings in aquifers that affect water storage comprise three general classes (Fletcher G. D., 1987);

1. Opening between individual particles in sandstone, conglomerate, sand, and gravel formation.
2. Crevices, joints, faults, and holes in igneous and metamorphic rocks.
3. Solution channels, caverns, and cavities in limestone and dolomite.

The shape of the openings in the rock or sediment, their size, volume, and interconnection all play a vital part in the hydraulic characteristics of an aquifer (Fletcher G. D., 1987). However, most rocks can hold some water and they vary a great deal in their ability to allow water to pass through. Permeability refers to the rock capacity to transmit a fluid through pores and fracture. In other words, permeability measures the relative ease of water flow and indicates the degree to which openings in a rock interconnect (Charles C. P. & Diane H. C., 2008). The sediments/rocks porosity and permeability are presented in Table 2.1.3–1

Table 2.1.3 – 1. Porosity and permeability of sediments and rocks. Most of sandstone, conglomerates and sand (Clean) – gravel sediments are “porous” and permeable. Unfractured crystalline rocks are impermeable. Shale and clay sediments can have substantial porosity, but low permeability because their pores are too small to permit easy water passage (Charles C. P. & Diane H. C., 2008**).**

Porosity and Permeability of Sediments and Rocks

Sediment	Porosity (%)	Permeability
Gravel	25 to 40	Excellent
Sand (clean)	30 to 50	Good to excellent
Silt	35 to 50	Moderate
Clay	35 to 80	Poor
Glacial till	10 to 20	Poor to moderate
Rock		
Conglomerate	10 to 30	Moderate to excellent
Sandstone		
Well-sorted, little cement	20 to 30	Good to very good
Average	10 to 20	Moderate to good
Poorly sorted, well-cemented	0 to 10	Poor to moderate
Shale	0 to 30	Very poor to poor
Limestone, dolomite	0 to 20	Poor to good
Cavernous limestone	up to 50	Excellent
Crystalline rock		
Unfractured	0 to 5	Very poor
Fractured	5 to 10	Poor
Volcanic rocks	0 to 50	Poor to excellent

According to “Exploration and Groundwater Mapping in Kamphaengphet province at scale 1:100,000” (DGR, 2001) and “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces (DGR, 2010), both unconsolidated and consolidated rocks aquifers are presented in Figure 2.1.3–1, their cross-sections are presented in Figure 2.1.3-2 – 2.1.3-7 and can be classified chrono – hydrogeological stratigraphy in ascending order (oldest – youngest). Details are as follows:

(1) **Consolidated-rocks aquifers** – consists of various aquifers which are classified hydrogeological stratigraphy in ascending order (oldest to youngest) as follows:

a. **Igneous-rock aquifers** –consists of 2 aquifers as follows ;

i. **Granitic rocks aquifers (Gr)** – Depth to aquifers are approximately 5–90 meters. Their majority appear in highly steep – lower mountain ranges within upper part on the west of Kosamphinakhon, Mueng Kamphaengphet, and Khlong Lan districts. These aquifers are composed of various kinds of Triassic granitic rocks (Trgr), including quartz-biotite granite, fine-grained hornblende granite, light green coarse-grained granodiorite.

ii. **Volcanic rocks aquifers (Vc)** – Depth to aquifers are approximately 5–40 meters. Their majority appear in low mountains and monadnock zone aligning in north – south direction at Kosamphinakhon district and they are composed of rhyolite, andesite, agglomerate, tuff and rhyolitic tuff.

b. **Sedimentary and Metamorphic aquifers** - consists of various aquifers which are classified hydrogeological stratigraphy in ascending order (oldest to youngest) as follows :

i. **Precambrian Metamorphic aquifers (P€mm)** – Depth to aquifers are approximately 25-30 meters and their yields are 3-4 cubic meters per hour. These aquifers generally appear in the western part of Kamphangphet province such as Klong Suan Mak, Khun Nam Yen mountain, and Klong Wang Chao up steam. These aquifers composing of Lens gneiss, Biotite-schist, and cal-silicate

ii. **Cambrian metamorphic aquifers (€mm)** – Depth to aquifers are 50 meters at the most and their yields are 2-3 cubic meters per hour. This aquifers occurred in Klong Suan Mak. These aquifers are composed of yellowish brown massive quartzite and arkosic sandstone.

iii. **Silurian – Devonian metamorphic aquifers (SDmm)** – Depth to aquifers are approximately45-55 meters and their yields are 2-5 cubic meters per hour. Their majority appear within Khao Lawein at Khanu Woralaksaburi districts of Kamphaengphet province. The aquifers are composed of phyletic tuff, rhyolitic tuff, greywacke, and some part of phyllite interbeded with quartzite.

iv. **Ordovician limestone aquifers (Oc)** – Depth to aquifers are approximately 30-40 meter and their yields are 2-5 cubic meters per hour. These aquifers appear in Ban Pong Nam Ron, Klong Lan district, and marble in Pran Kratai district and comprised massive limestone and marble.

v. **Carboniferous Metasediment aquifers (Cms)** – Depth to aquifers are approximately 40-50 meter and their yields are 2-3 cubic meter per hour. The aquifers appear in Ban Wangmaidang, Yod lek foothill, Pran Kratai district, align through Nang Tong mountain, Ban Wangparn and are composed of greenish gray shale, sandstone and conglomerate. The upper part is sandstone and shale of Lan Hoi Formation in Mae Tha Group which are low grade metamorphism rocks.

vi. **Lower Khorat aquifers (TRJlk)** – Depth to aquifers are approximately 20-30 meter and their yields are two cubic meter per hour at the most. These aquifers appear in Khaosangampang, Khaochonkarn, Khaoprikthai and are composed of Mesozoic rocks, especially Khaodang formation in lower Khorat Groups, This aquifers are volcanic clastic conglomerate, interbedded with sandstone and red shale which have less fracture / fault.

(2) **Unconsolidated-rocks aquifers** – consist of various aquifers and are classified hydrogeological stratigraphy in ascending order (oldest to youngest) as follows :

a. **Old terrace aquifers (Qot)** – expose some parts in upper western of Phran Kratai, Kosamphinakhon, Khlong Lan, Mueang Kamphaengphet, Pang Sila Thong, and Khanu Woralaksaburi districts, reaching general thickness of approximately 20-150 meters. They comprise coarse sand and coarse clayey gravel sediments, sub angular to rounded, poor to well sorting. These aquifers occur in flat plain area overlain by the younger terrace aquifers (Qyt1). However, distinct specific yield is examined where a better yield is expected in the middle of basin compare to that of rim portion of the basin. On the other hand, at the upper western rim of groundwater basin where high terrace sediments accumulation is observed, are attain to rather good hydraulic characteristics for groundwater storage.

b. **Young terrace aquifers (Qyt)** – expose at the western parts of Phran Kratai, Kosamphinakhon and Mueang Kamphaengphet districts. Depth to aquifers is approximately 5–40 meters with varying thickness of approximately 15-20 meters. The aquifers mainly comprise rather thick clay bed and/or sandy clay, intercalated with sand and gravel bulb, particularly thick sandy gravels are observed. These aquifers occur in flat plain area, overlain alluvial fan and flood plain aquifers.

c. **Alluvial fan aquifers (Qaf1 & Qaf2)** – underlies the flood plain aquifers, which have thick clay bed at the bottom. These aquifers extend throughout the study area over both sides of the Ping River alluvial plains. The Alluvial fan aquifers can be sub-divided into 2 sub aquifers as follows:

   i. **Old alluvial fan aquifers (Qaf2)**–exposes from the lower west of Mueang Kamphaengphet district, towards the west side alluvial plains of Ping River in Mueang Kamphaenghet district. They occurred during middle Pleistocene period and comprise coarse sand and gravel attaining grain size bigger than 20 millimeters, angular to rounded, poor to well of sorting.

   ii. **Young alluvial fan aquifers (Qaf1)** - exposes from east of Kosamphinakhon, Muaeng Kamphaengphet, Khlong Khlung districts, where the alluvial sand and gravel sediments stretch to 5-20 meters thickness along the Ping River. They comprise coarse sand and gravel attaining grain size of fine sand to gravel of approximately 5 millimeters, sub rounded to rounded, medium to well sorting.

Both aquifers have similar hydraulic characteristics. Nevertheless, they occurred in different ages and sediment sources. However, they are potential shallow groundwater resource of Kamphaengphet province.

d. **Alluvial, Flood-plain aquifers (Qa, Qfd)** – They are the youngest aquifers (approximately 1,000 – 10,000 years before present) laying the uppermost layer of all unconsolidated-rocks aquifers and extend throughout Kamphaengphet province. In the high topography regions, they may underlie by shallow bedrock that mostly exposes at the north-western part of the area. The ordinary sediments thickness are approximately 6-15 meters and may increase to 15-35 meters on approaching towards flood plain of Ping River and its tributaries. The thickest layer could reach up to 48 meters. The Ping River flood-plain normally extends within Kosamphinakhon, Muaeng Kamphaengphet, Khlong Khlung districts where the alluvial sand and gravel sediments stretch to 5-20 meters thickness along the Ping River, attaining grain size of fine sand to gravel approximately 5 millimeters, sub rounded to rounded, medium to well sorting. Nevertheless, further away from the main river and its tributaries, comprising clay, silt, sand and gravel sediments are in-homogeneously mixed-up.

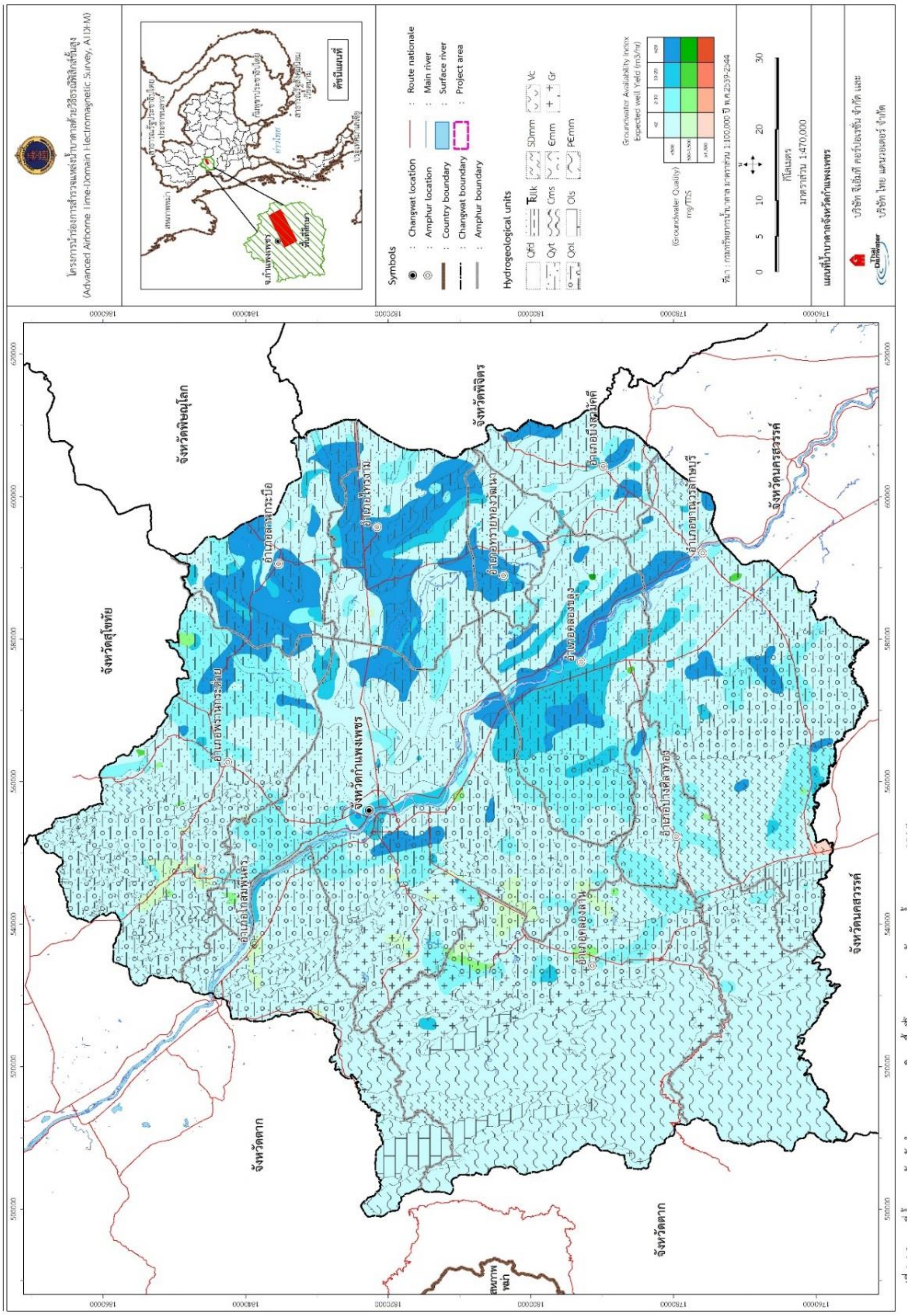


Figure 2.1.3–1. Hydrogeological units, expected well yield, and groundwater quality in Kamphaengphet province (Refers to “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces (DGR, 2010))

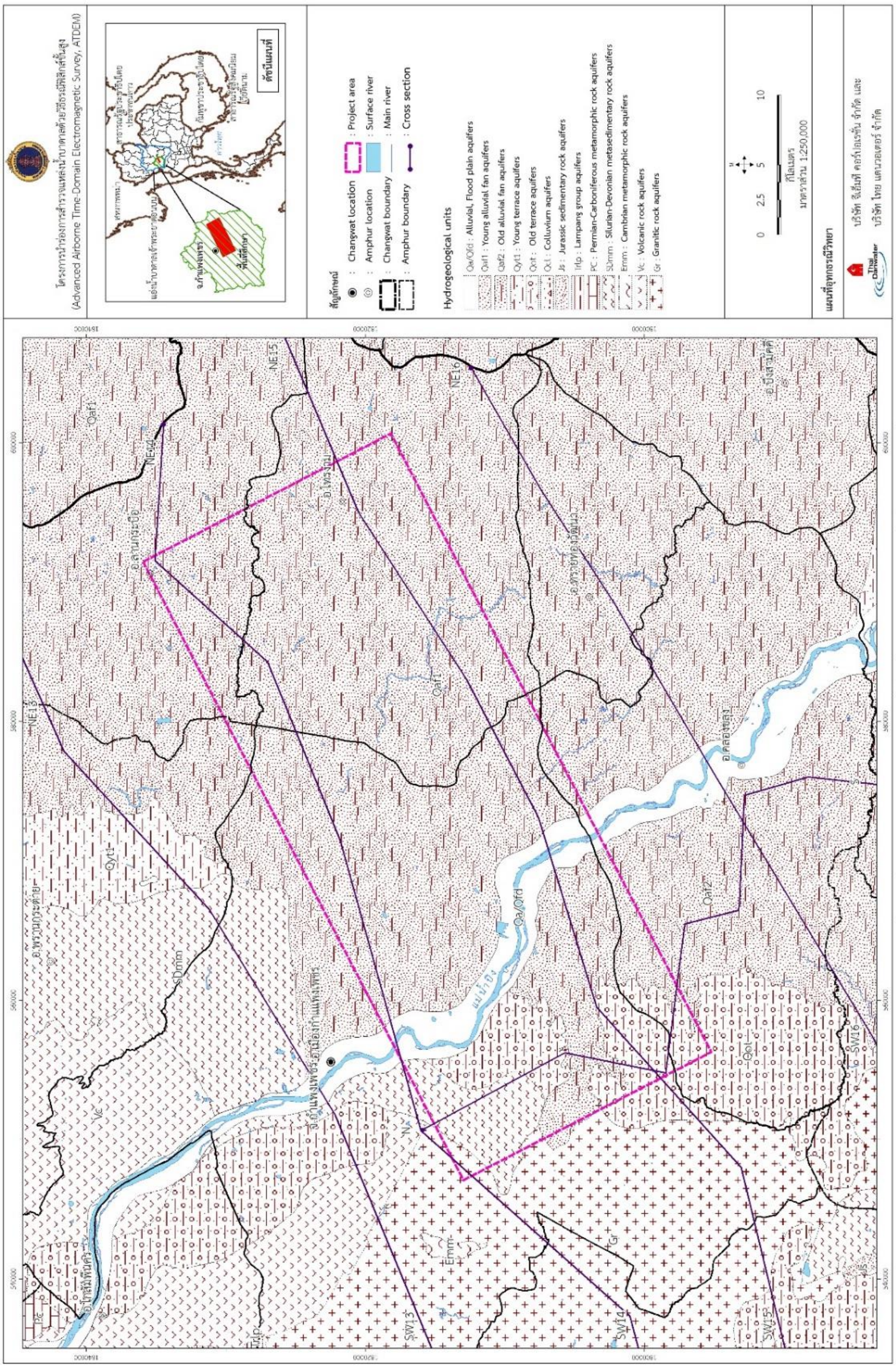


Figure 2.1.3–2. Hydrogeological map and cross-section lines (Purple Lines) and ATDEM project area (Blue block) (Refers to "Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin" at scale 1:50,000 Area 3: Nakhon Sawan, Tak and Kamphaengphet provinces **(**DGR, 2010**)**)

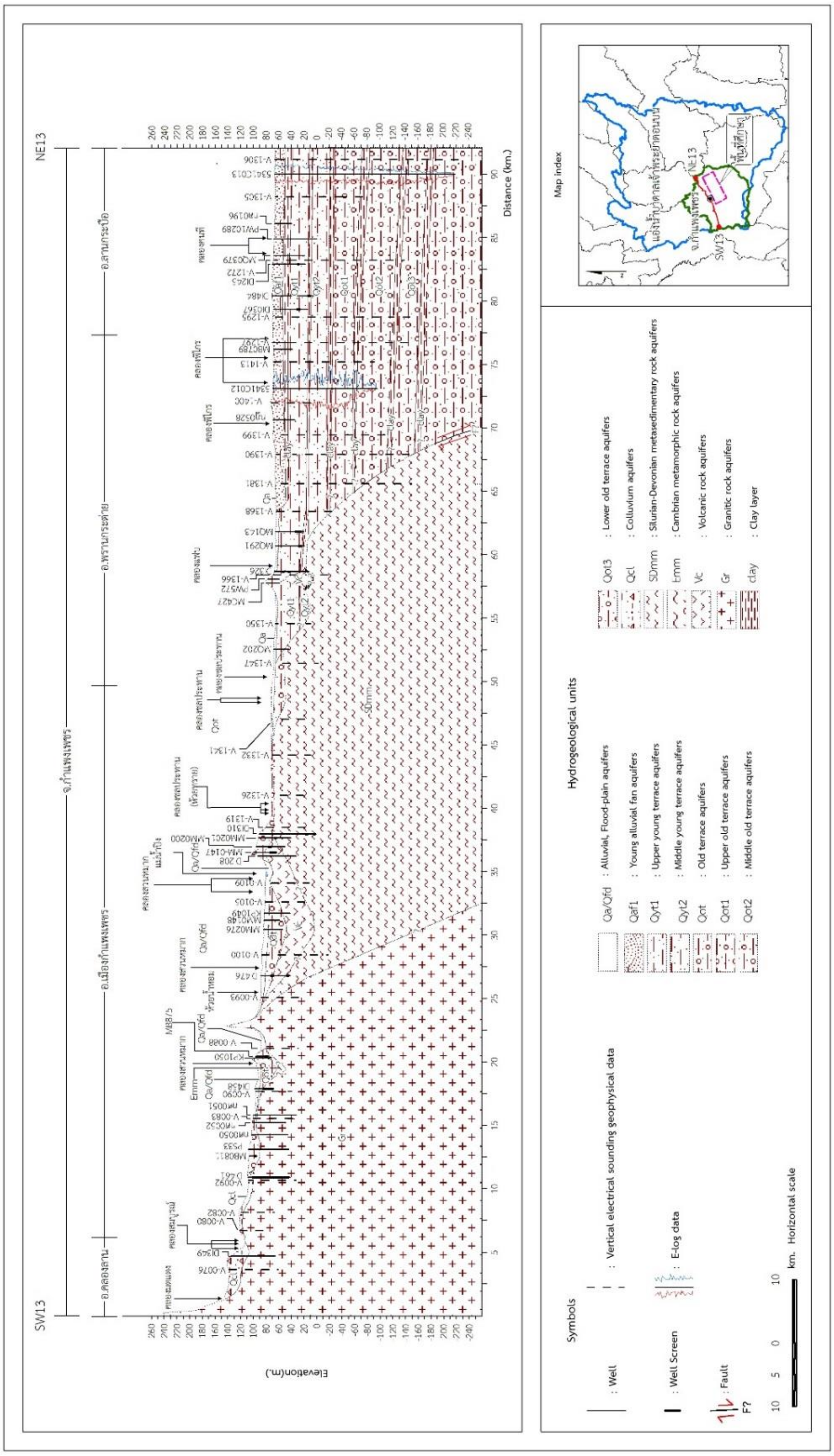


Figure 2.1.3–3. SW13-NE13 cross section across through Muang Kamphaengphet, Klong Lan, Phran Kratai, Lan Krabue district, Kamphaengphet province. (Refers to “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces (DGR, 2010))

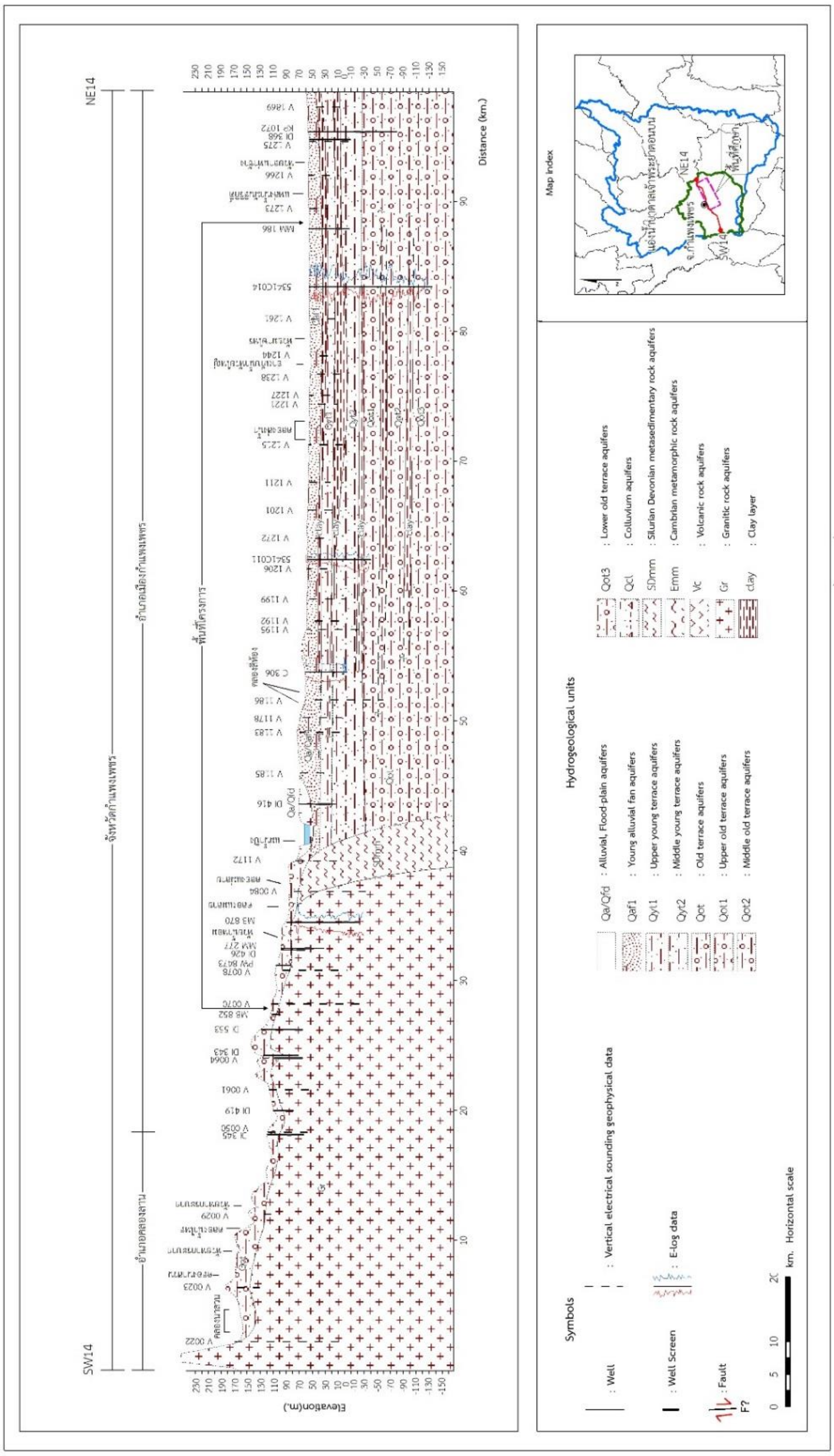


Figure 2.1.3–4. SW14-NE14 cross section across through Muang Kamphaengphet, Klong Lan district, Kamphaengphet province (Refers to “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces (DGR, 2010))

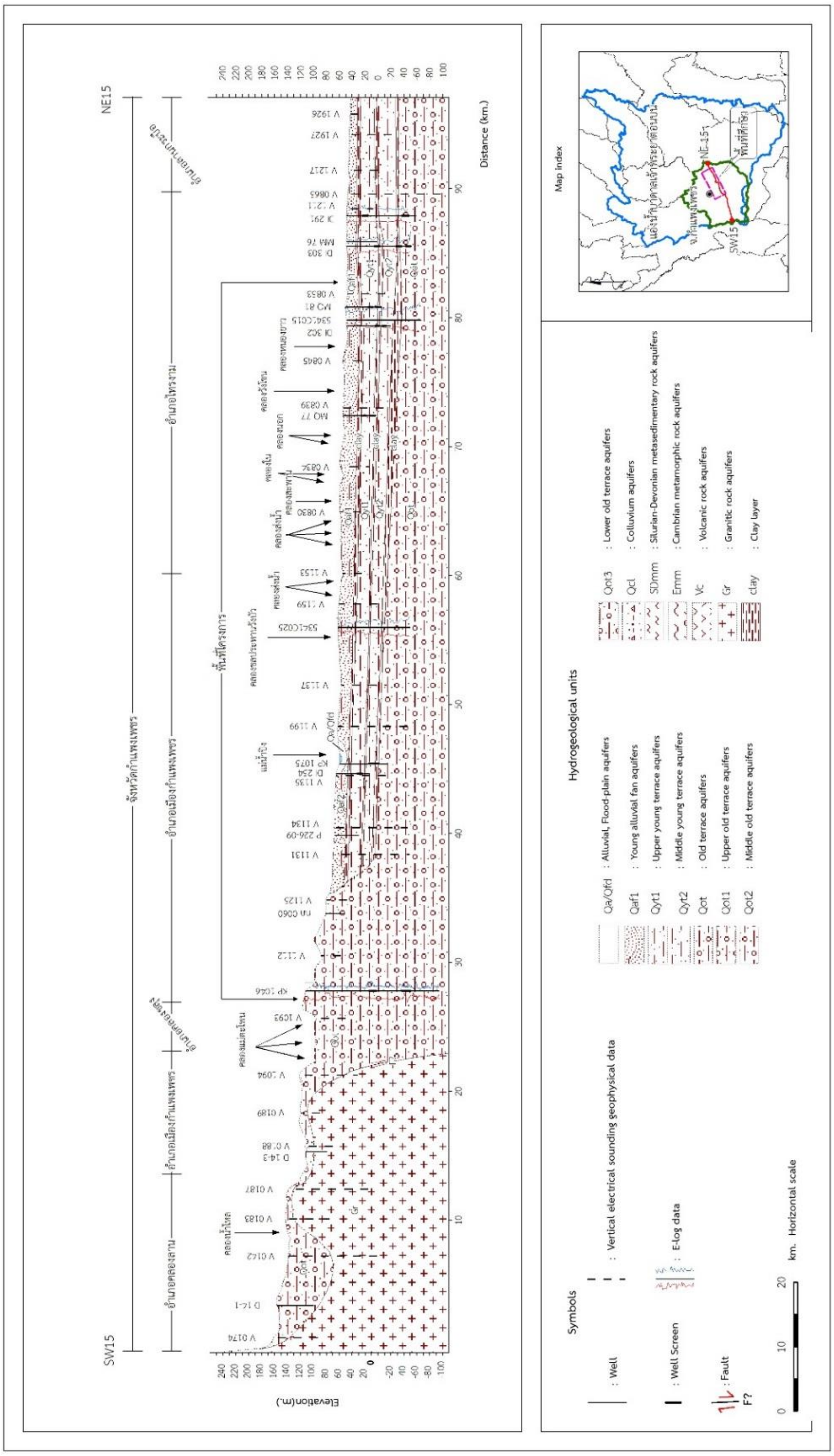


Figure 2.1.3–5. SW15-NE15 cross section across through Muang Kamphaengphet, Klong Lan, Klong Klung, Sai Ngam, Lan Krabue district, Kamphaengphet province (Refers to “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces(DGR, 2010))

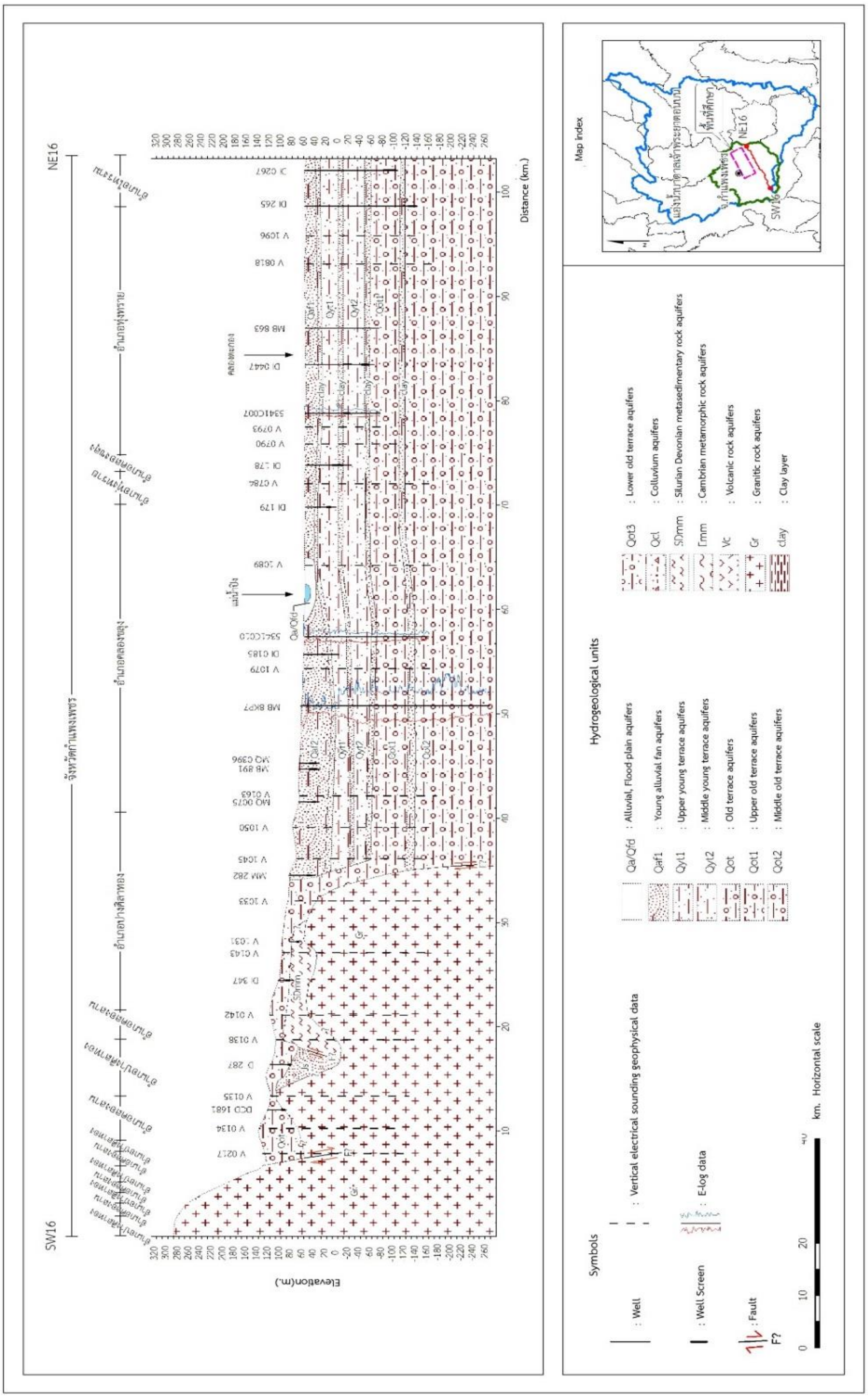


Figure 2.1.3–6. SW16-NE16 cross section across through Pang Silathong, Klong Lan, Klong Klung, Thung Sai, Sai Ngam district, Kamphaengphet province. (Refers to "Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin" at scale 1:50,000 Area 3: Nakhonsawan, Tak, Kamphaengphet provinces (DGR, 2010))

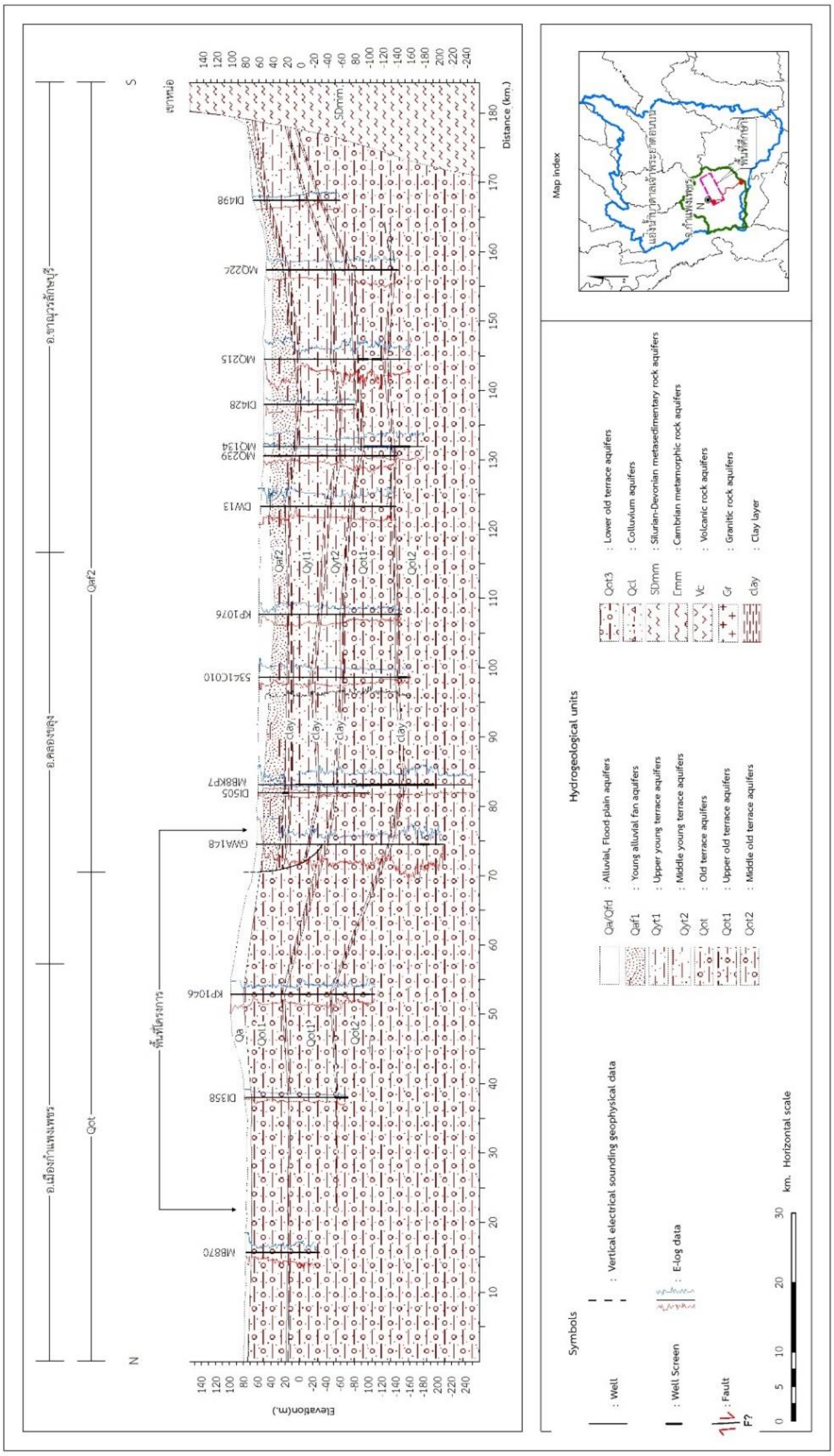


Figure 2.1.3–7. North-South cross section across through Muang Kamphaengphet, Khanu Wrlaksburi, Klong Klung, district, Kamphaengphet province. (Refers to “Detailed Exploration and Groundwater Mapping within the Upper Chao Phraya Basin” at scale 1:50,000 Area 3: Nakhonsawan, Tak and Kamphaengphet provinces (DGR, 2010))

2.2 Electrical and Electromagnetic Prospecting Method

The electrical resistivity surveys measurement can be classified into various methods, depending on tools and technique such as direct current resistivity survey, induced polarization, self-potential survey, electromagnetic survey, and etc. The exploration process used electrical prospecting as an integral part for long times in wide range such as engineering geophysics, environmental geophysics, gas and oil prospecting through mining and groundwater management.

2.2.1 Electrical resistivity principle

"Electrical resistivity" is intrinsic property of material which describes capability of material that quantifies how well a material oppose electric currents flow through it, and its reciprocal is called "electrical conductivity" or that measures a material's ability electric current conduction.

The electrical resistivity surveys measurement can classify soil/rock characteristic and their structures by relying on specific electrical conductivity properties of different soil/rock (Figure2.2.1-1).Generally, the majority of rocks and sediments mainly consists of silicate minerals such as Nesosilicates group comprising olivine, garnet, zircon, and etc.; sorosilicates group comprising epidote, lawsonite, etc.; inosilicates group comprising pyroxene and amphibole, and etc., which are significant dielectric (nonconductor), in other words, they have low electrical conductivity (High resistivity), with the exception of hematite, magnetite, carbon, graphite, pyrite, and most of all metal minerals. As a result, conduction is mostly electrolytic depends on porosity, permeability, electrolyte concentration, moisture contents, temperature, composition of clay content, and geological structure such as fault, crack, cavity, vug, and fracture

Porosity is one of the most valuable factors. It occurs in fault, fracture, crack, vug (dissolved cavities in limestone or dolomite) and etc., in igneous and metamorphic rocks, and intergranular void in sedimentary rocks and/or soils.

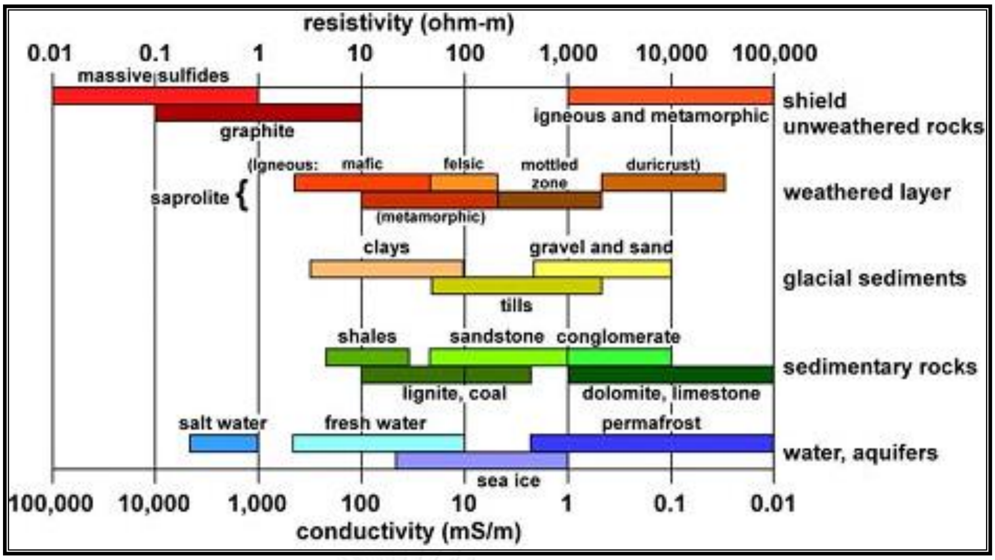
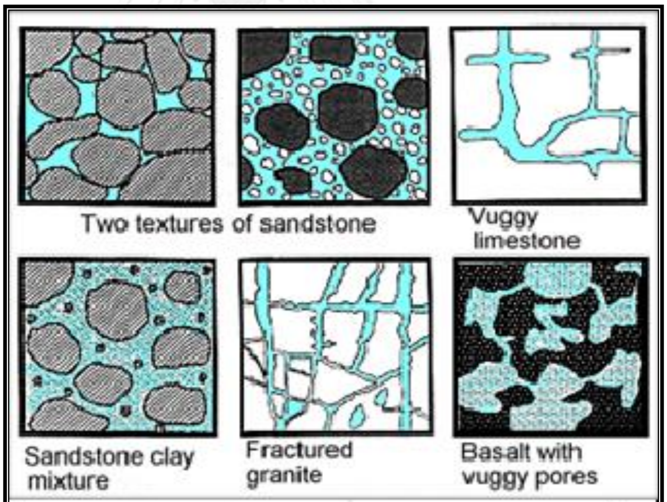


Figure 2.2.1-1. Typical ranges of electrical resistivity (ohm-m) or conductivity (mS/m) for selected earth materials such as rocks, soils, massive sulfides, and etc. (Palacky, 1988) (http://emgeo.sdsu.edu/images/0.3.jpg)



Rock or Formation	Porosity	Ratio $\frac{\rho_s}{\rho_l}$
Igneous and metamorphic rocks	½– 2	100
Dense limestones and sandstones	3– 4	50 –100
Clays and sands in general	8–15	20 – 40
Porous clays, sands, sandstone, cellular limestones, and dolomites	15–40	3 – 20
Marl, loess, clay, and sandy soil	40–75	1.5– 4
Peat, diatomaceous earth	80–90	1.0– 1.5

Figure 2.2.1-2. Porosity in hard rocks. The lower part is a ratio column which is bulk resistivity divided by electrolyte resistivity (Geonics TN5, 1980)

Vuggy porosity (composed of larger discrete voids) may have very low permeability, resulting in low resistivity when measured by direct current resistivity techniques. Nevertheless, inductively resistivity measurement such as electromagnetic method may show higher resistivity values because of the fact that currents induced by oscillating electromagnetic fields do not have to flow over large distances.

This research use airborne time-domain electromagnetic survey as secondary data in combination with direct current resistivity survey consisting of 2 methods, 1D vertical electrical sounding and 2D multi-electrode system. Details are as follows:

2.2.2 Direct current resistivity method

The direct current resistivity sounding method for carrying out measurements involves the transmission into the earth of direct current, which are generally carried out using four electrode arrays at the surface, and usually placed symmetrically on a line. One electrode pair for introducing current passing through the ground is called "current electrodes" or "source electrode" and the other electrode pair for measurement of the potential associated with the current field affected by voltage difference is called "potential electrode" or "receiver electrode". The electrodes position, the transmitted current, and the resistivity distribution in the ground can affect the potential dissimilarity.

The field work measures the current amplitude value *(I)* that through the source electrodes, and the voltage difference *(ΔV)*, between the receiver electrodes. The data results can calculate the ground apparent resistivity (ρ_a), which is used in the geophysical and geological interpretation.

(1) In addition, direct current resistivity methods in relation to fundamental concepts are related to Ohm's law, current patterns in the ground, apparent resistivity, electrode configuration, and penetration depth. **Ohm's law**– is presented below (Figure 2.2.2-1) ;

$$\Delta V = RI \qquad (1)$$

ΔV is the potential difference measured across conductor in "volts" unit.

R is the resistance of the conductor in "ohms" unit.

I is the current through the conductor in "amperes" unit.

Refer to law several generalizations formulated by Ohm, is considered as

$$\vec{E} = \rho \cdot \vec{J} \qquad (2)$$

E is the electric field at that area in "V/m" unit.

J is the current density at that area in resistive material in "A/m^2" unit.

ρ is a material resistivity in "Ωm" unit.

uniform conductor electrical resistance is given in terms of resistivity by;

$$R = \rho \frac{L}{A} \qquad (3)$$

l or L is the length of the conductor in "meters" unit.

a or A is cross-section area in "m^2" unit. (Round wire $a = \pi r^2$, r is radius)

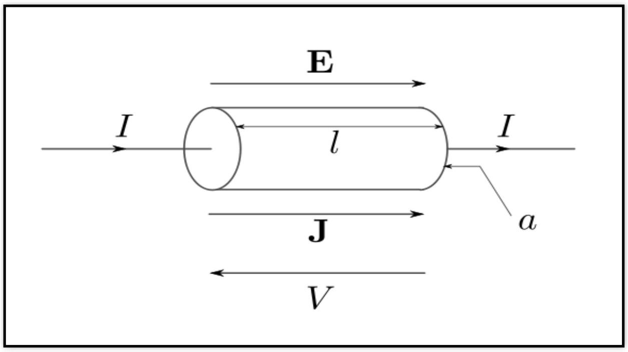


Figure 2.2.2-1 Current flowing through a uniform cylindrical conductor (such as round wire) with a uniform field (Spinning S., 2009)

By using equation **(1)** and equation **(3)**, the new equation can be formulated as;

$$\rho = \frac{\Delta VA}{IL}$$

Ohm's law implies that there is proportionality between the current injected by the source electrodes and the potential measured over the receiver electrodes.

(2) Ground current patterns – are presented with as follows

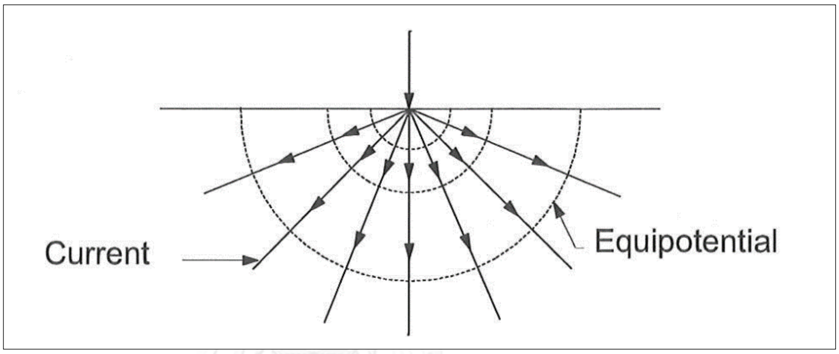


Figure 2.2.2-2. Electrical current and potential field around a single point electrode (Niel, B. C., 2008)

In figure 2.2.2–2 the electrode sends current into homogenous layer.In addition, the electrode discharge radial current flow equally in all direction and equipotential surfaces. According to "Ohm's law",the equation can be formulated as below;

$$V_r = \frac{\rho I}{2\pi r} \qquad \textbf{(4)}$$

From this equation, "I" is the current, "ρ" is the resistivity, and "*r*" is the distance between the observation point and the point source. The observation point can be anywhere in the layer.

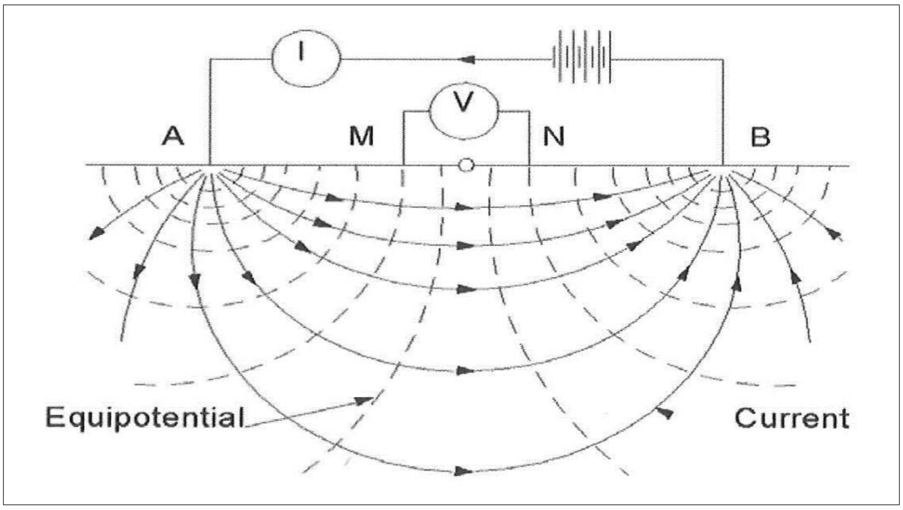


Figure 2.2.2-3 Electrical current and potential field in homogenous ground. A and B are source electrodes, M and N are receiver electrodes (Niel, B. C., 2008)

The current pattern around two electrodes is presented in figure 2.2.2-3, showing a vertical section in a homogeneous layer through the line, connecting the source electrodes (A & B), and receiver electrodes (M & N) respectively. (Niel, B. C., 2008)

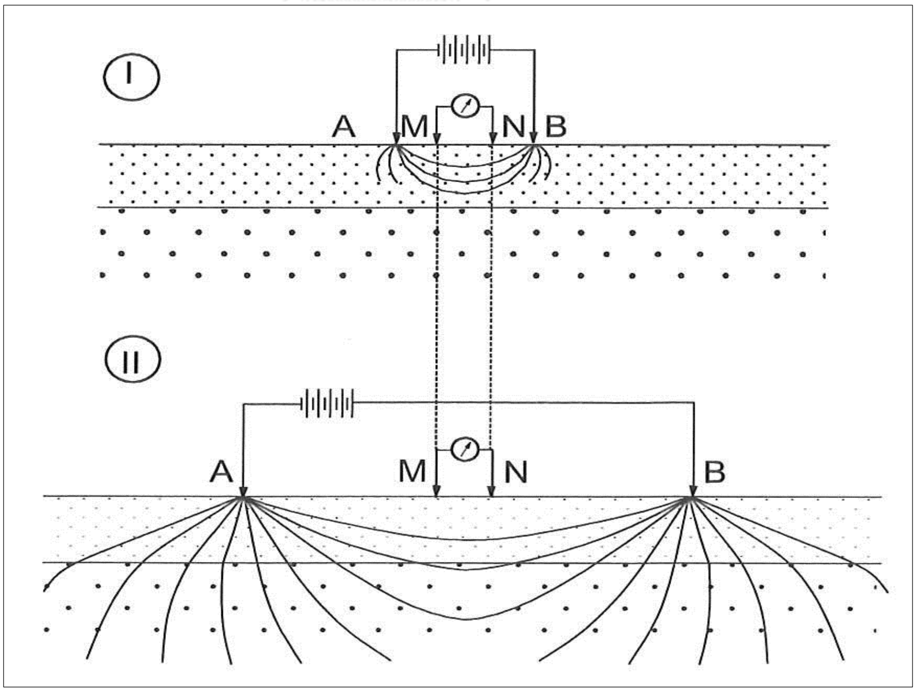


Figure 2.2.2-4. Current pattern over 2-layer earth is different distance of the source electrodes of a Schlumberger configuration. (Niel, B. C., 2008)

Figure 2.2.2-4 Shows the two different electrode configurations which are presented with increasing electrode distance and increasingly deeper parts of a 2-layer earth (Niel, B. C., 2008). The picture shows that only the longer electrode distance can affect the lower layer resistivity. The penetration depth increases with increasing distance between the source and the receiver electrodes.

(3) **Apparent resistivity** – The homogenous layer resistivity can be specified by concurrently measuring the potential V, and the current I, by using equation (4)

$$V_r = \frac{\rho I}{2\pi r} \Rightarrow \rho = 2\pi r \cdot \frac{V}{I} = K \cdot \frac{V}{I}$$

For four-electrodes configuration; the source electrode pair, and the receiver electrode pair, the potential difference between the receiver electrodes can be discovered by using the superposition principle is showed as below;

$$\Delta V = V_m - V_n = (V_{AM} - V_{BM}) - (V_{AN} - V_{BN})$$

$$\Downarrow$$

$$\Delta V = \frac{\rho I}{2\pi|AM|} - \frac{\rho I}{2\pi|BM|} - \frac{\rho I}{2\pi|AN|} + \frac{\rho I}{2\pi|BN|}$$

$$\Downarrow$$

$$\Delta V = \frac{\rho I}{2\pi}\left[\frac{1}{|AM|} - \frac{1}{|BM|} - \frac{1}{|AN|} + \frac{1}{|BN|}\right]$$

In addition, it is seen that the resistivity can be determined as: (Niel, B. C., 2008)

$$\rho = \frac{\Delta V}{I} \cdot 2\pi\left[\frac{1}{|AM|} - \frac{1}{|BM|} - \frac{1}{|AN|} + \frac{1}{|BN|}\right]^{-1} = K \cdot \frac{\Delta V}{I} \quad \textbf{(5)}$$

K is the geometrical factor that determined exclusively by the geometry of the electrode configuration. The equation **(5)** can be formulated for calculate the apparent resistivity "ρ_a" presented as below;

$$\rho_a = K \cdot \frac{\Delta V}{I} \quad , \quad K = 2\pi\left[\frac{1}{|AM|} - \frac{1}{|BM|} - \frac{1}{|AN|} + \frac{1}{|BN|}\right]^{-1}$$

The apparent resistivity must give the same measurement as the actual one. It therefore expresses a sort of average resistivity within the volume where the current flows. (Niel, B. C., 2008)

(4) **Electrode configuration** – There are several kinds of electrodes configurations that can use for both sounding and profiling, have proven popular for a wide range of geophysics applications (Loke, 1999). Nevertheless, it remains worthwhile to briefly discuss a few of the traditional electrode configuration in order to gain insight into the capabilities of the resistivity method and explore the advantages and disadvantages of the various electrode configuration in terms of depth penetration, lateral resolution, ease of deployment, and signal to noise ratio (Zonge et al, 2005). The traditional four electrodes configuration consists of schlumberger array, wenner array, and dipole-dipole array (Figure2.2.2-5).

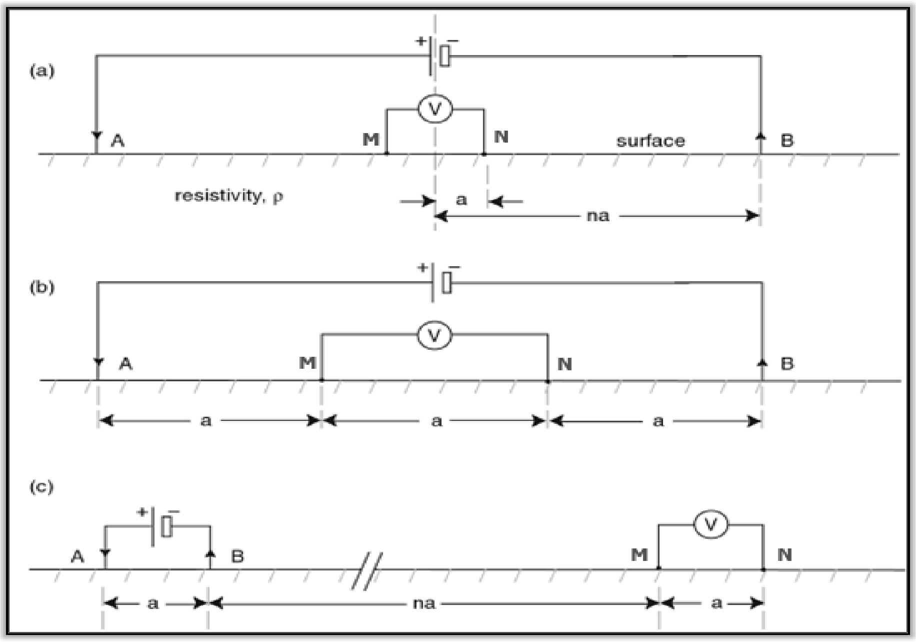


Figure 2.2.2-5. Traditional four electrodes configuration (a) Schlumberger, (b) Wenner, (c) Dipole-Dipole (Modified from Mark E. E., 2013)

The comparisons various electrode configurations about their advantage and disadvantage are studied by Loke (1999), Niel B. C. (2008), and Mark E. E. (2013). Details are described as below;

(a) **Schlumberger array** – shows in figure2.2.2-5a. This is designed for sounding to determine the earth resistivity depth profile beneath a single location. Its sounding can achieve outstanding depth penetration with adequately wide source electrodes separations. This array has moderate lateral and vertical resolution and is suitable for both of horizontal and vertical structures. The signal – noise ratio is moderate to good. The penetration depth is approximately 0.64 x (AB/2) in homogeneous layer, AB is the distance between the source electrodes.

(b) **Wenner array** – shows in figure2.2.2-5b. This is designed for lateral profiling to determine the earth resistivity at roughly constant depth of penetration. This array is relatively sensitive to vertical changes in subsurface resistivity but insensitive to horizontal changes in subsurface resistivity, making it good in mapping horizontal structures such as sills or sedimentary layers, but relatively poor in mapping vertical structures, such as dykes and cavities. The signal – noise ratio is generally good because the receiver electrode MN are situated in the central part of array and near the source electrode AB. The penetration depth is approximately 0.30 x “a” in homogeneous layer, “a” is the distance between the receiver electrodes.

(c) **Dipole-Dipole array** – shows figure2.2.2-5c. This takes advantages of both Wenner lateral profiling and Schlumberger depth sounding. The array is very sensitive to horizontal changes in subsurface resistivity but relatively insensitive to vertical changes in subsurface resistivity, making it good in mapping vertical structures, such as dykes and cavities, but relatively poor in mapping horizontal structures such as sills or sedimentary layers. The signal – noise ratio is very low because it has high noise values. The penetration depth approximately 0.22L in homogeneous layer, L is maximum electrode distance.

(5) Interpretation and Model computation – the quantitative interpretation of dc resistivity sounding has been the subject of numerous mathematical modeling studies for several decades (Milton B. D. & Carl H. S. 1988). All physical laws are formulated in a forward manner as direct problem. This means that if one knows the model described by the distribution of the model parameters, it is possible to calculate the model response (the response that one would measure in field situation) (Niels N. B., 2008). The model that is in accordance with real geology in the study area is interpreted by apparent resistivity curve plot with electrode separation that is measured in fieldwork. In this study use IPI2WIN, ProsysII, RES2DIV, and GEOSCENE3D programs for process and interoperate raw data.

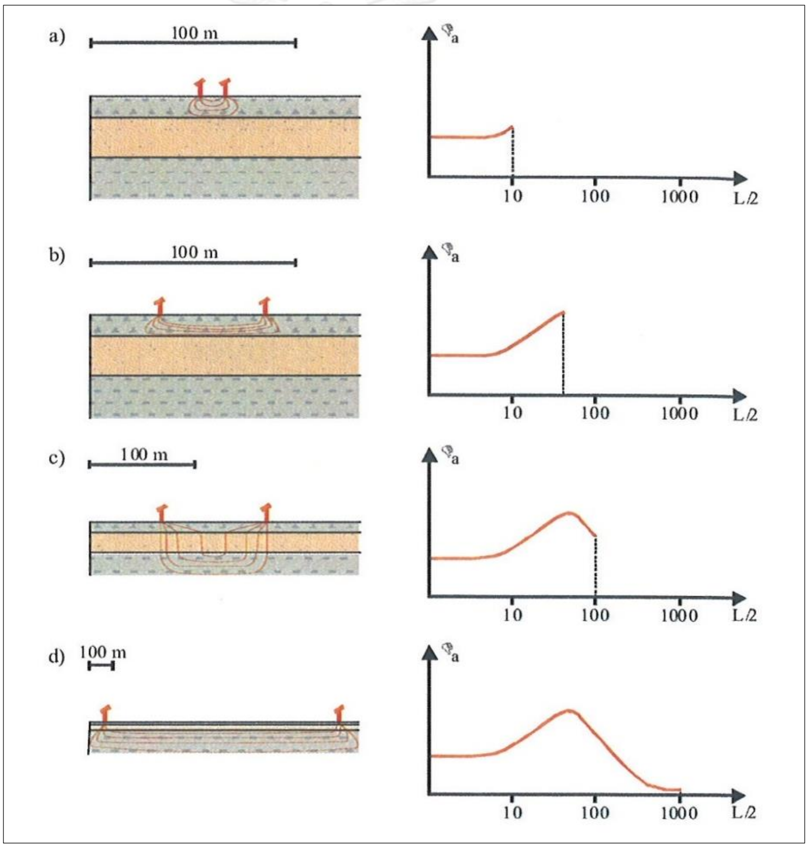


Figure2.2.2-6 Shows current flow in clay interbedded with sand sediment layers with apparent resistivity curve plot with electrode separation, a) the current mainly flow in 1 layer through clay layer (low resistivity) over sand layer (high resistivity), b) the current flow affected by 2 layers including clay and sand, c) the current flow distributed in layers, and d) the current mainly flow in 3 layers.

2.2.3 Airborne time-domain electromagnetic method

Electromagnetic method broadly consists of two types, one is frequency-domain technique and the other is time-domain technique. The frequency technique has disadvantage for groundwater exploration in sedimentary area. The distinct advantage of time-domain technique when compared with frequency technique is investigation depth. Time-domain technique investigation depth is 250-350 meters, but frequency-domain technique investigation depth is limited to 50-80 meters only.

(1) **Measuring technique and Principle** - All electromagnetic geophysical methods (TEM) are based on the fact that a magnetic field varies in time and thus, according to the Maxwell equation, induce an electrical current in the surroundings (GEUS, 2010). TEM method uses direct current which is generated by transmitter coil. The current passes through a wire loop that causes electromagnetic field called "Primary field" are stopped suddenly and this Primary field penetrate through subsurface. According to the Faraday's law, subsurface consists of conductive inhomogeneous layers causing "eddy current" which is induced by primary field in the subsurface layer. The eddy current flows through layers and generates other electromagnetic field called "secondary field" that can be measured by receiver coil on wire loop (Figure 2.2.3-1).

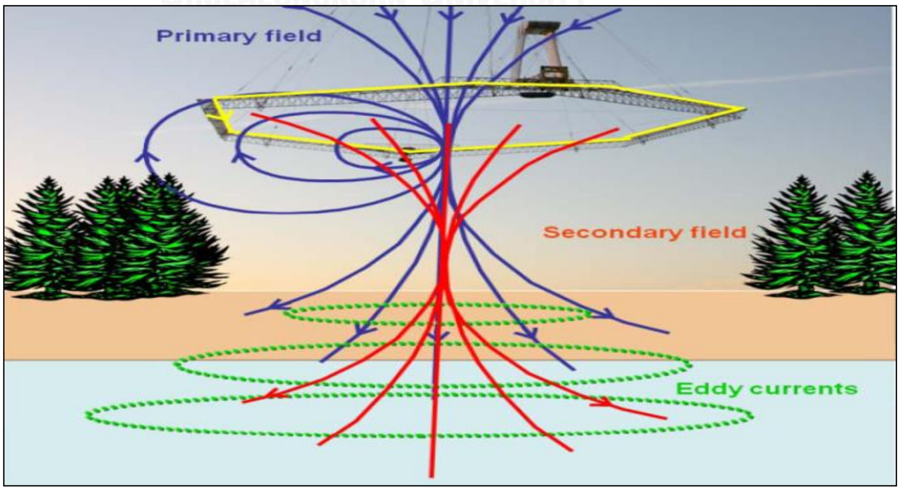


Figure 2.2.3-1. Primary field, secondary field and eddy currents (GEUS, 2010)

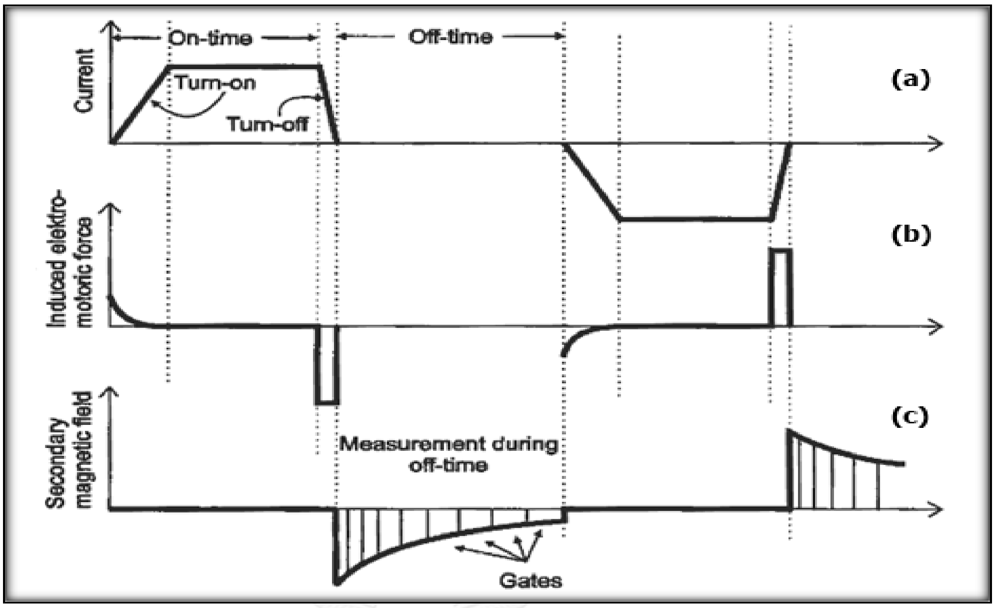


Figure 2.2.3-2. TEM current pattern, (a) presents the current in the transmitter loop, (b) presents the induced electromagnetic force in the ground, (c) presents the secondary field measured in receiver coil. (Auken E., 2003)

(2) **Airborne TEM instruments** – In this study, “SkyTEM” data is used as secondary data. A list of instruments are presented below (Figure 2.2.3-3 to Figure 2.2.3-5 ;

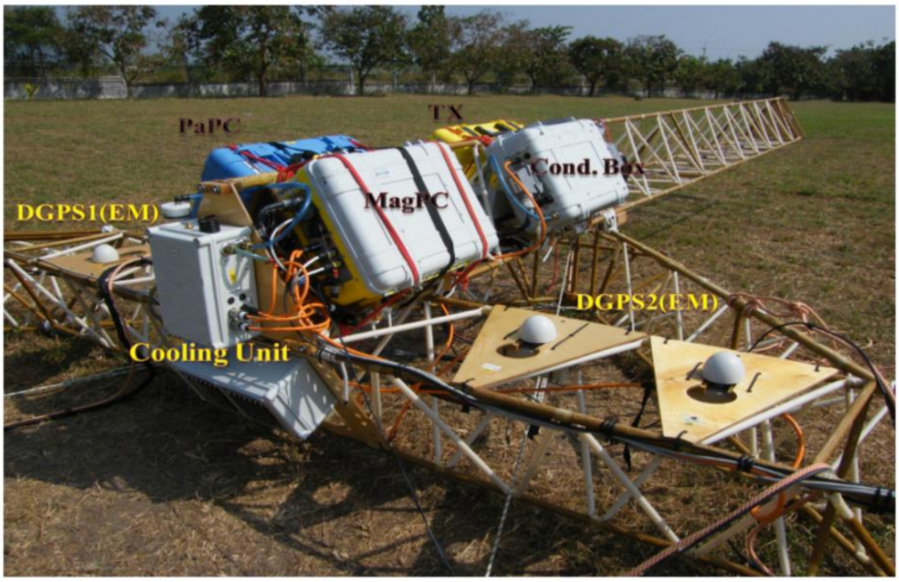


Figure 2.2.3-3. Transmitter coil (TX), Magnetic field instrument (MagPC), Differential GPS (DGPS), Control box set (PaPc, Cond.Box, and Cooling Unit) (DGR, 2011)

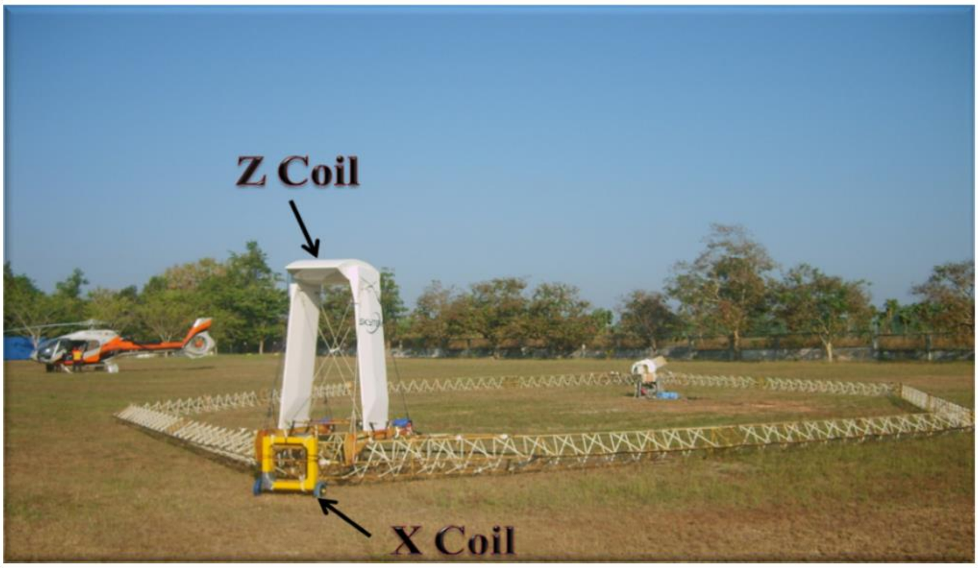


Figure 2.2.3-4. 2 receiver coils measure secondary field in different direction, Z measures vertical direction, X measures horizontal direction. (DGR, 2011)

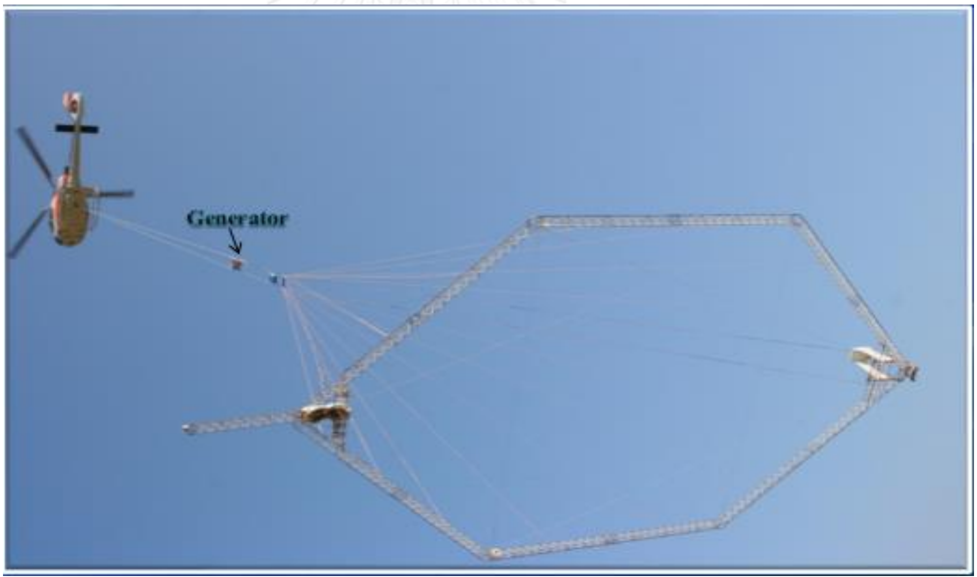


Figure 2.2.3-5. Generator and SkyTEM flame (DGR, 2011).

SkyTEM instrumental system setup on duel transmitter mode, one is low moment mode that yields maximum resolution at near surface geological structure and the other is high moment mode that yields a better resolution of geological structure features at deeper depth (DGR, 2013).

(3) TEM Interpretation– The secondary field can be measured in terms of impulse responses (db/dt) that is the induced electromotoric force, which is proportional to the time derivative of the magnetic flux passing the coil. The impulse responses (db/dt) can be applied to apparent resistivity form, and use for interpretation procedure. The curves graphs are presented in figure 2.2.3-6 and figure 2.2.3-7

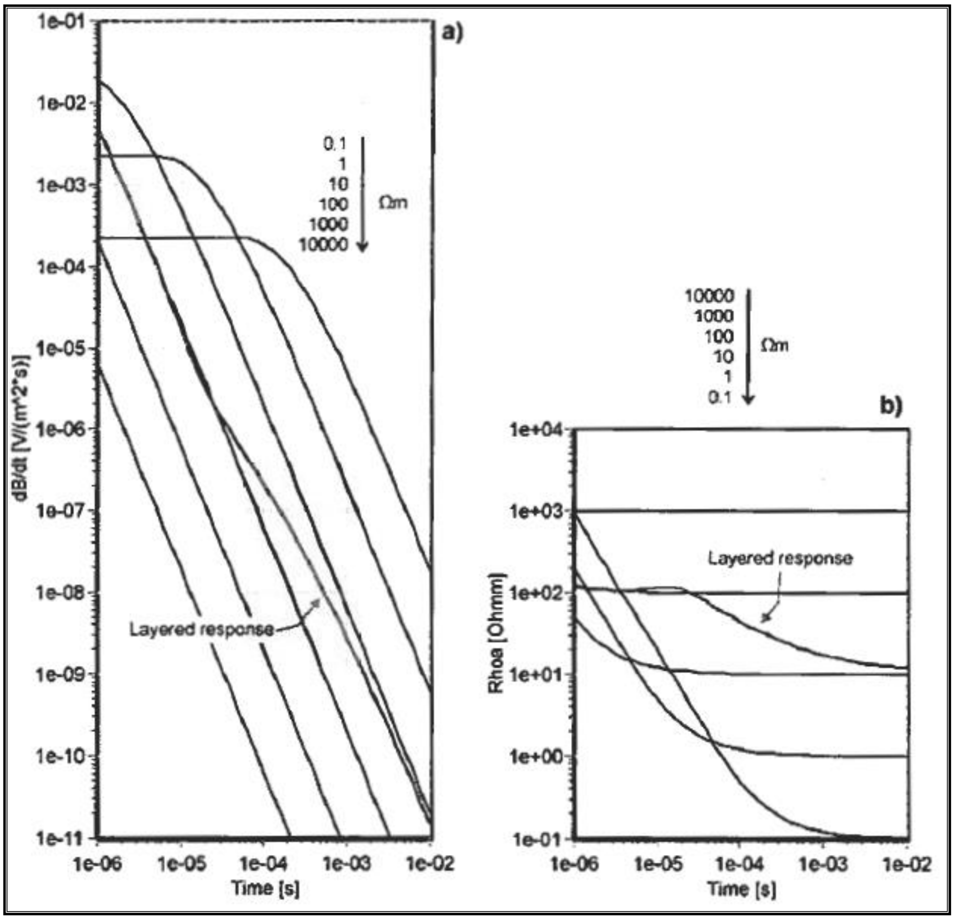


Figure2.2.3-6 (a) Presents impulse response (db/dt) with varying resistivity. The same curves converted to apparent resistivity are shown in (b). The line is response of a two-layer subsurface with 100 ohm.meters in layer 1, and 10 ohm.meters in layer 2. Layer 1 thickness is 40 m. (Auken E., 2003)

(4) TEM advantages and limitation – The advantages of the airborne time-domain electromagnetic method are that it can be carried out quickly in a regional scale and in a deep investigation depth. However, this method outstandingly analyzes low–rather high resistivity underground layer approximately 80 – 100 Ohm.meters.

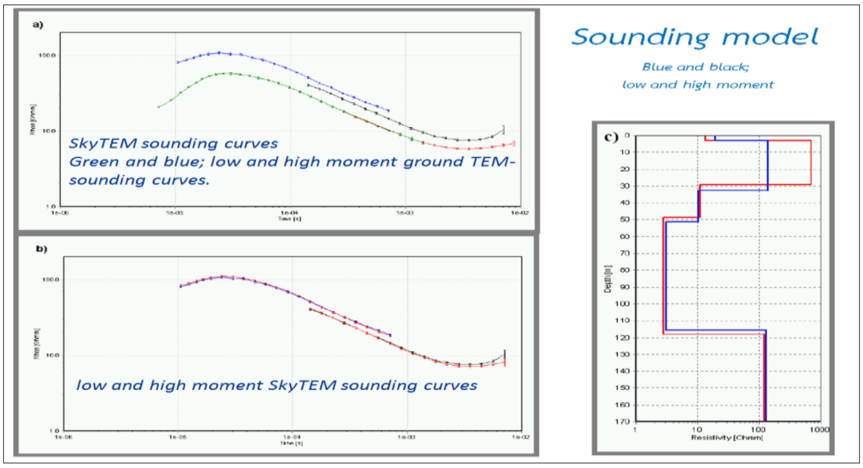


Figure2.2.3-7 Sounding curve and inverted model for TEM sounding consisting of low moment curve (blue) and high moment curve (black)

However, it is very sensitive with coupling noise that appears due to induced currents in all manmade electrical conductor such as cables, rails, power lines, metal fences, and etc. Data coupling effect cannot be interpreted and should be deleted. Furthermore, TEM method has only limited sensitivity to high resistivity layers. Figure 2.2.3-7 presents the fact that high resistivity layers cannot generate any significant responses because the curves are almost no different from others.

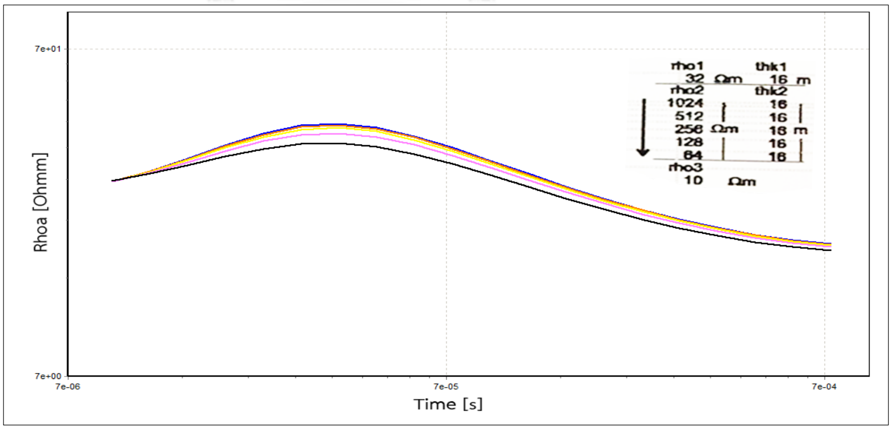


Figure2.2.3-8 Resistivity equivalence. The top layer is 32 ohm.meters. The second layer is varied from 64 ohm.meters – 1024 ohm.meters. The bottom layer is 10 ohm.meters. The top and second layer thickness are 16 meters. (Modified from Auken E., 2003)

2.3 The study area

In this research, the study sites were selected by focusing on the airborne time-domain electromagnetic survey project area (ATDEM) in Muang Kamphaengphet district within Kamphaengphet provinces, induced by the remarkable anomalies which are high resistivity value, distinctly clear shape and lineaments within appropriate area size.

2.3.1 Size and location of study area

The study area covers two Tambon consisting of most area in “Klong Mae Lai” and other is in “Wang Tong” within the northwest part of a ATDEM area covering 1.2 square kilometers which is total of 81 vertical electrical sounding points, and 2.6 kilometers 2D multi-electrode lines have been achieved (Figure 2.3.1-1 and 2.3.1-2).

2.3.2 Topography, Geology, and hydrogeology

The study area topography shows Klong Mae Lai river line up along northeast-southwest direction. Most of the area is rather smooth and flat and is overlain by sandy-clay sediment. Their elevations range from 91 meters to 105 meters above mean sea level and incline from west to east of study area.

The study area geology is composed of 2 geological units as follows :

1). Silurian-Devonian rocks. The rocks consist of greenish gray, very fined grained phyletic shale, and green phyllite comprising quartz and mica, which showing fracture cleavage and foliation. Their yields are 2-5 cubic meters per hour, which are 45-55 meters aquifer depth.

2). Old terrace deposits, these deposits of gravel and sandy clay sediment are mostly composed of quartz, feldspar, and clastics. Particularly, these unit sediments were cemented by iron oxide and changed to laterite. The old terrace deposits thickness are approximately 25-45 meters.

'The primary potential aquifer is Silurian-Devonian metamorphic aquifers storing water in cleavage, joint, fault and/or fracture. The major lineament is in north-south direction which is presented in mean resistivity map from TEM resistivity value.

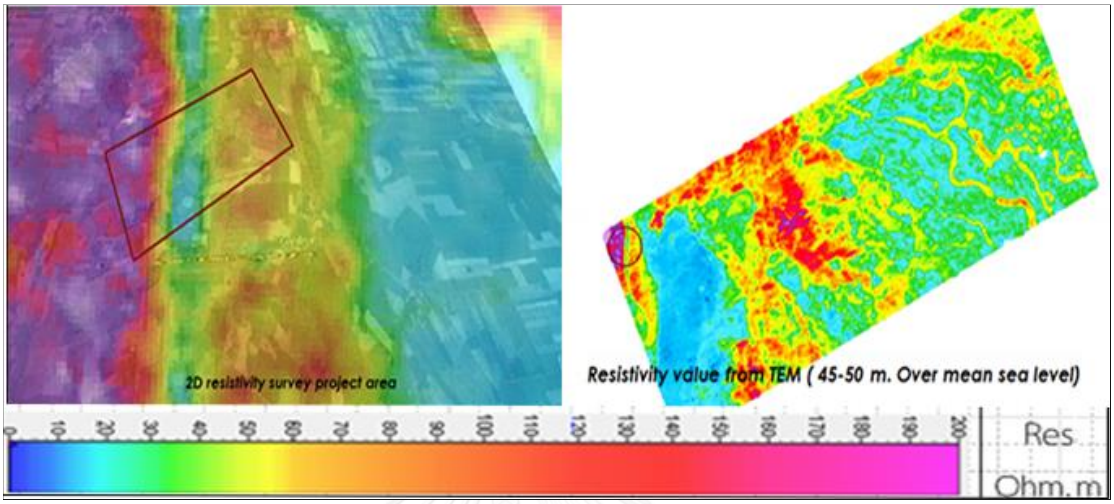


Figure 2.3.1-1.(Right) Mean resistivity from ATDEM project at depth 45-50 m. over mean sea level. (Left) The study area (black frame) is in the northwest part of ATDEM project.

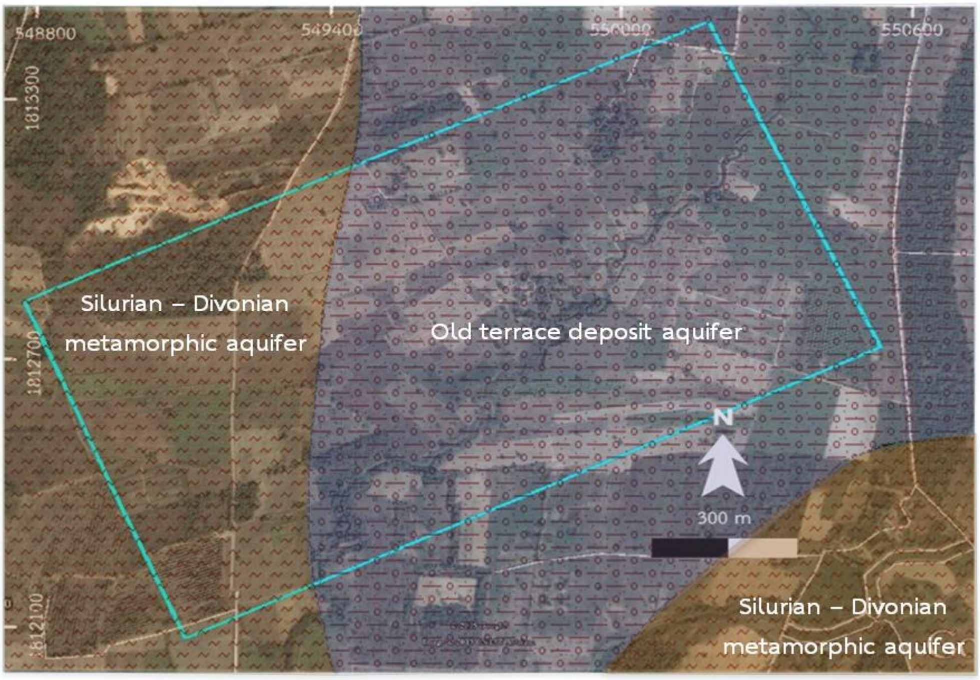


Figure 2.3.1-2. The study area satellite image in Tambon Klong Mae Lai and Wang Tong, Muang Kamphaengphet district, Kamphaengphet province, in white frame are overlaid by hydrogeological unit. (DGR, 2001)

CHAPTER III
METHODOLOGY

This study methodology is divided into six stages including (1) Literature review and secondary data collection, (2) The study area survey, (3) Vertical electrical sounding (VES) geophysical survey, (4) 2D multi-electrode geophysical survey, (5) Data processing, and (6) Data interpretation.

3.1 Literature review and secondary data collection

Literature review related to general information of Kamphaengphet province such as geology and geological stratigraphy units, Structural geology, hydrogeology and hydrogeological stratigraphy units, electrical resistivity principle, direct current resistivity method, and airborne time-domain electromagnetic method. Furthermore, this study collects several secondary data including geological data, hydrogeological data, well logging data consisting of electrical log and lithology log, satellite image and airborne time-domain geophysical data, for interpretation.

3.2 The study area survey

After literature review and secondary data collection procedure, the exploration and field check in the study area where the geophysical resistivity has been mapped from ATDEM project show the significant anomalies which contrast with resistivity value, distinctly clear shape and lineament in the northwest part were implemented carefully together with many kind of tools such as geological compass, ruler, Kamphaengphet map scale 1:50,000, GPS receiver, and etc. Generally, GPS receiver is used for providing location and time information and marking interesting points such as large water pond, or lateritic borrow pit on the map. This survey helps for planning the geophysical VES point location and 2D multi-electrode survey line direction because some fields such as dense sugarcane field or miry overgrown weed area are unable to survey and the researcher needs to find new point location or change line of direction and length. (Figure 3.2-1)

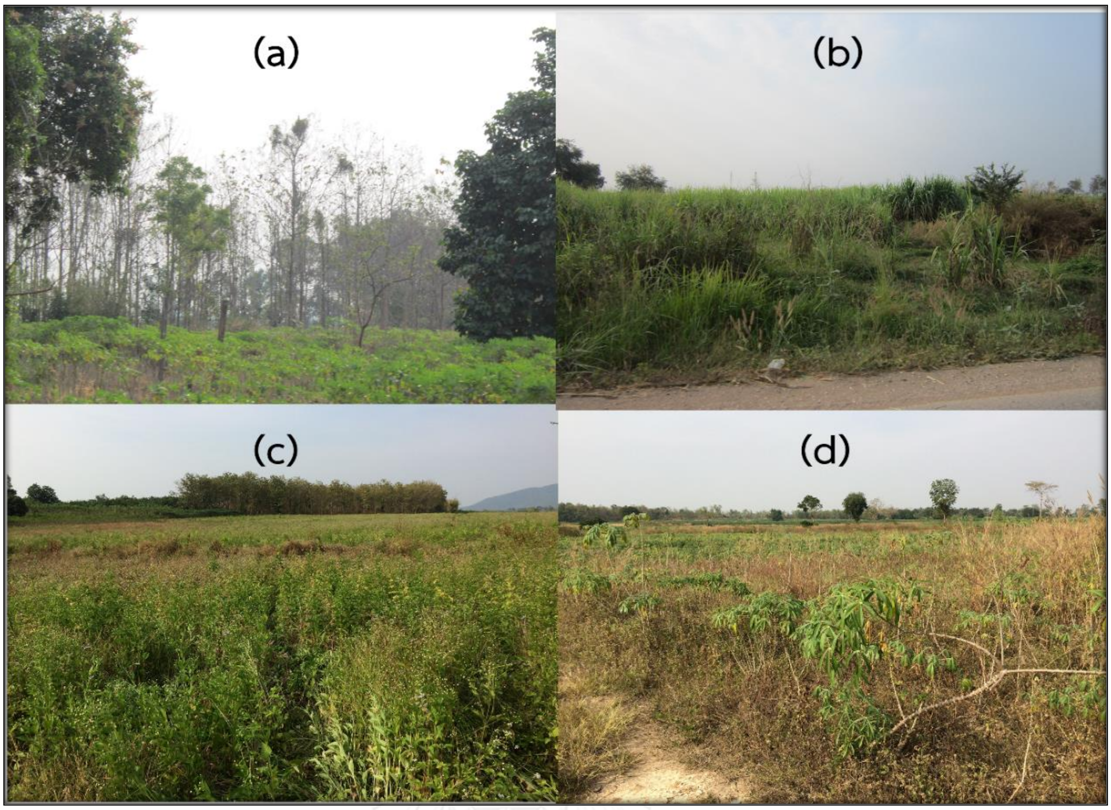


Figure3.2-1. Some landuse in the study area, (a) high tree area with dense weed near cassava field, (b) sugarcane field, (c) overgrown weed area, (d) cassava field

3.3 Vertical electrical sounding geophysical survey (VES)

Vertical electrical sounding survey is a low cost geophysical exploration applied to investigate bedrock and deep subsurface layer. This study uses schlumberger array configuration that can achieve outstanding depth penetration with adequately wide source electrodes separations and is suitable for both horizontal and vertical structures. Schlumberger array technique is an easy configuration and conveniently increases the source electrode (AB electrode) separation for increasing the investigation depth. This survey design offers the widest source electrode distance up to 300 meters width and explores at least 75 investigation points. This study uses “SUEBSAK SS 09” instruments composing of one control box, two cable rolls, four electrode poles as parts of receiver electrode pair, source electrode pair, hammers, and a one battery. (Figure 3.3-1)

Figure3.3-1. The VES instruments and survey method (a) control box measures voltage and current, (b) two cable rolls are connected with source electrode at cable terminal, (c) some electrode poles which have at least 1 pair is receiver electrode are connected with control box, and other pair is source electrode are connected with cable rolls , (d) instrument emplacement have battery, cable rolls, and etc., are connected with control box, (e) connecting cable and electrode pole and, (f) hammering the electrode pole to the ground.

3.4 2D multi-electrode resistivity survey

2D multi-electrode survey is applied to investigate detailed subsurface layers or explore proper structure zone in the study area. 2D multi-electrode consisting of 48 electrodes and 5 meters electrode spacing were applied for exploring local aquifer, especially, consolidated rock aquifer bearing water in its vug, fracture, or fault zone. This study uses dipole-dipole array configuration that is very sensitive to horizontal changes in subsurface resistivity, meaning that it is good in mapping vertical structures, such as dykes, and fractures or faults. The electrode separation section designed for this study area ranges from 235 meters to 515 meters, depending on geological structure, land use, cost, and time. “SYSCAL R1+ SWITCH 48” instruments made from one control box, two multi-core cable rolls, forty-eight electrodes, forty-eight jumper clips, hammers and a one battery are used in the study is well. (Figure 3.4-1)

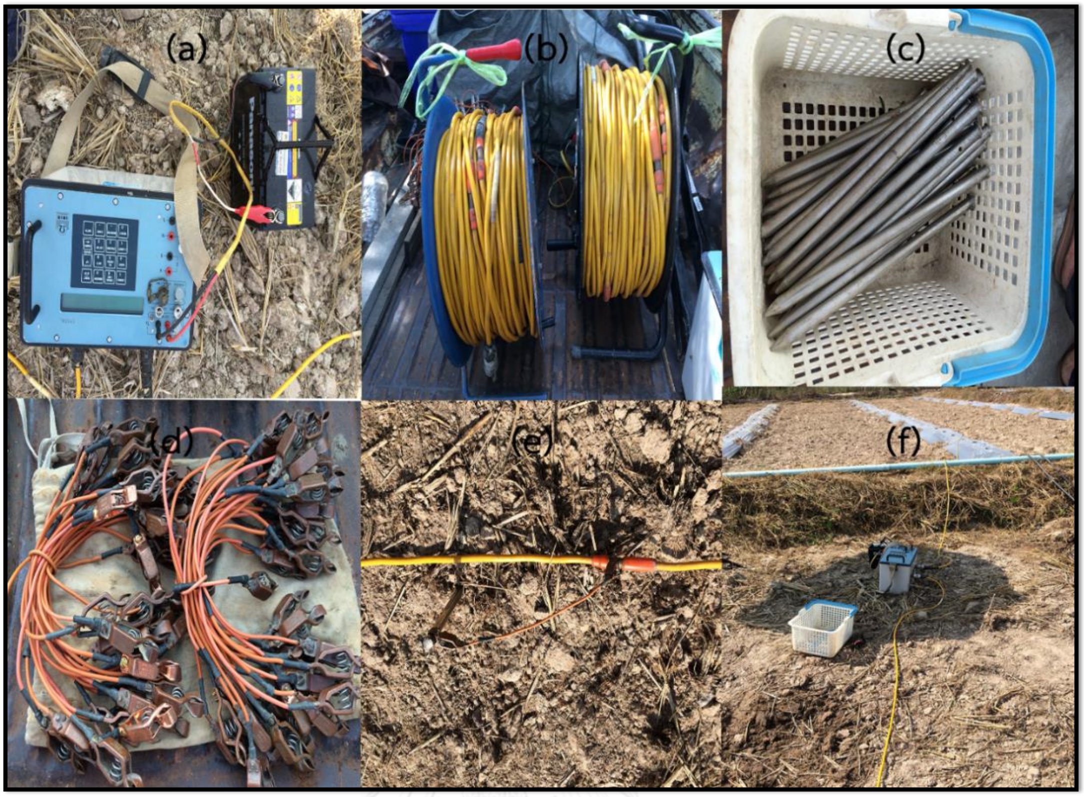


Figure3.4-1. The 2D multi-electrode instruments and survey method (a) control box and battery, (b) two multi-core cable rolls, (c) forty-eight electrode poles (d) forty-eight jumper clips, (e) showing the jumper clips that are used to connect multi-core cable with electrode pole , and (f) showing control box connected with 2 multi-core cables.

3.5 Data processing

Data processing is a procedure to produce significant data from raw data or field measuring data for interpretation in the next stage. Generally, raw data have some errors from human errors and/or instrument errors such as over value resistivity data, noise data and/or, coupling effect data, therefore, data adjustment is indispensable. The vertical electrical sounding geophysical survey data uses “IPI2WIN”for processing and calibrating, and 2D multi electrode geophysical survey data uses “ProsysII” for processing and calibrating (Figure 3.5-1).

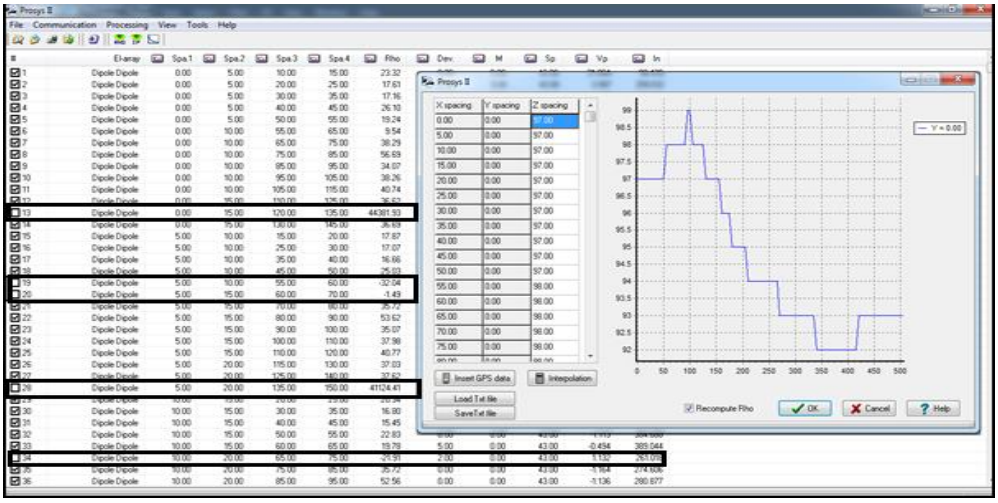


Figure3.5-1. The 2D multi-electrode resistivity survey data of Line1 in program “Prosys II” for data processing. Data elevations are adjusted in Z spacing column for precisely interpretation. Black frames showing irregular data are minus and immoderate apparent resistivity that should be eliminated before interpretation procedure. The processed data will be saved and exported to RES2DIV file format for model inversion and interpretation after adjusting and calibrating procedures.

3.6 Data interpretation

The data analysis and interpretation procedures combine all secondary data such as well-log data, airborne time-domain electromagnetic survey data, geology and geological unit data, hydrology and hydrogeological unit data, etc., with primary data including Vertical electrical sounding geophysical survey data and 2D multi electrode survey data. Data interpretation consists of geophysical model inversion by apparent resistivity curve calculation to classify subsurface layers, and hydrogeological / geological unit classification to analyze aquifers characteristic and groundwater potential respectively. The vertical electrical sounding geophysical survey data relies on “IPI2WIN” for interpretation. Figure3.6-1 showing 6 layers model inversion that can interpret layer 1 and 2 which are top unsaturated sandy-clay sediment. Layer 3 is saturated clay sediment and layer 4 is weathering phyllite. Layer 5 is weathering phyllite with fracture zone and is followed by layer 6, fresh phyllite. 2D multi electrode geophysical survey data relies on “RES2DIV” (Figure 3.6-2), and TEM sounding data relies on “GEOSCENE3D” for interpretation.

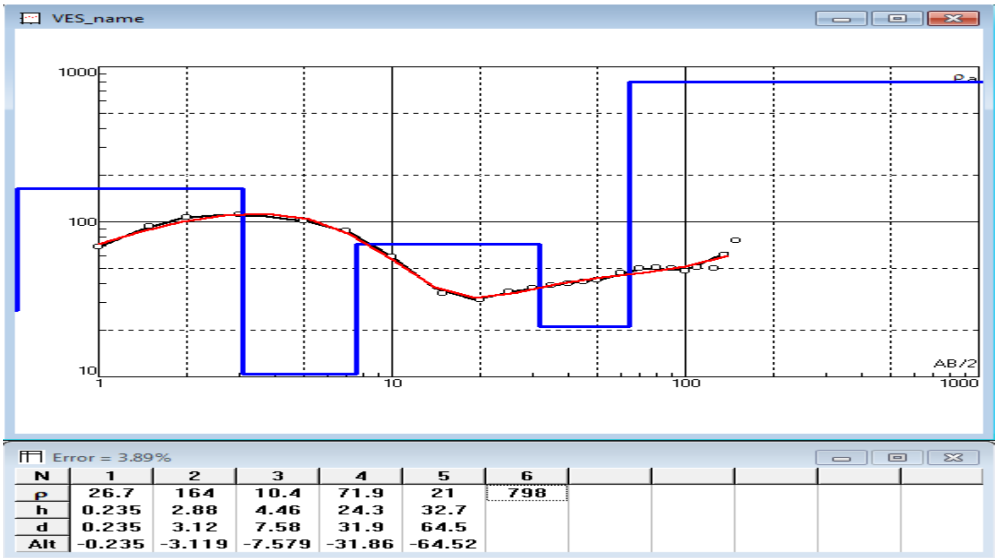


Figure3.6-1. Vertical electrical sounding geophysical survey data for model inversion of VES4_5 point in program “IPI2WIN” that consists of 6 layers model : 1.) Layer 1 is 26.7 Ωm. and 0.235 m. thickness. 2.) Layer 2 is 164 Ωm. And 2.88 m. thickness. 3.) Layer 3 is 10.4 Ωm and 4.46 m. thickness. 4.) Layer 4 is 71.9 Ωm and 24.3 m. thickness. 5.) Layer 5 is 21 Ωm and 32.7 m. thickness. 6.) Layer 6 is 798 Ωm.

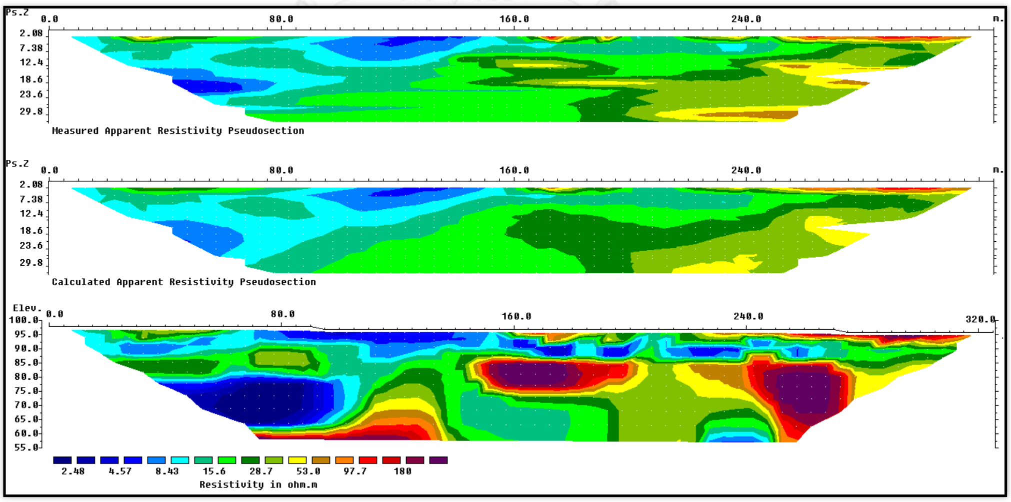


Figure3.6-2. 2D multi electrode geophysical pseudosection for model inversion of Line 4-2 in program “RES2DIV” that calculates measured apparent resistivity from processed data to true resistivity section with elevation, and resistivity scale bar.

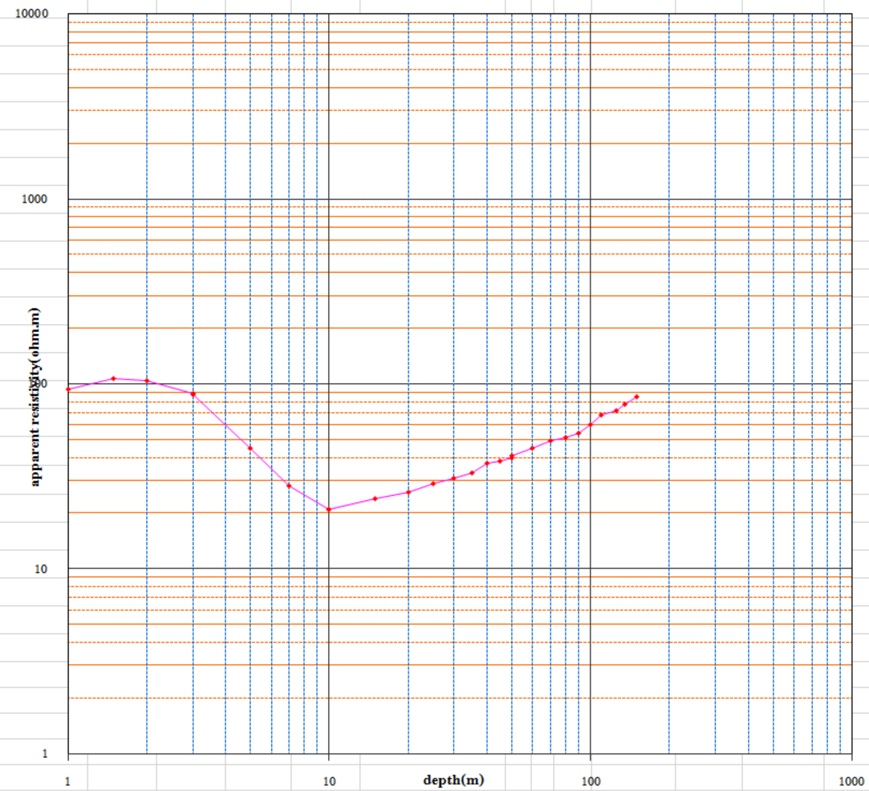
Table 3.3-1. VES geophysical survey raw data of “VES2-1” point.

THESIS	APPLICATION OF ELECTRICAL RESISTIVITY METHOD COMBINED WITH TIME DOMAIN ELECTROMAGNETIC DATA FOR CONCEPTUAL HYDROGEOLOGICAL MODELLING IN CHANGWAT KAMPHAENGPHET

หมายเลข			
หมายเลข	สถานที่ บ้านคลองละแวก	หมู่ที่ 1	ตำบล คลองไม้ลาย
2_1	อำเภอ เมือง	จังหวัด กำแพงเพชร	ระวางแผนที่
	Zone 47b	UTM E 550138	UTM N 1813173
	วันสำรวจ	ผู้สำรวจ	

Operator					
AB/2	MN	K	R	Res (Ohm-m)	หมายเหตุ
1	0.5	5.9	15.952	94	
1.5	0.5	13.8	7.782	107	
2	0.5	24.8	4.202	104	
3	0.5	56.2	1.584	89	
3	2	12.6	6.920	87	
5	2	37.7	1.193	45	
7	2	75.4	0.371	28	
10	2	155.6	0.135	21	
10	5	58.9	0.356	21	
15	5	137.5	0.175	24	
20	5	247.5	0.105	26	
25	5	388.9	0.075	29	
30	5	561.8	0.055	31	
35	5	766.1	0.043	33	
40	5	1001.8	0.037	37	
45	5	1268.9	0.030	38	
50	5	1567.5	0.026	40	
50	20	377.1	0.109	41	
60	20	550.0	0.082	45	
70	20	754.3	0.065	49	
80	20	990.0	0.052	51	
90	20	1257.1	0.043	54	
100	20	1555.7	0.039	60	
110	20	1885.7	0.036	68	
125	20	2439.6	0.030	72	
135	20	2848.2	0.027	77	
150	20	3520.0	0.024	85	

หมายเหตุ



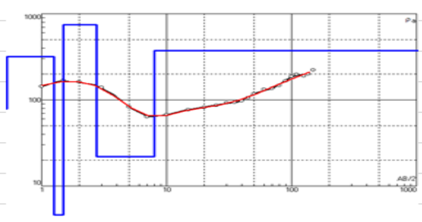
CHAPTER IV
RESULTS

This research uses direct-current resistivity inversion data which are interpreted from apparent resistivity curve plot with electrode spacing (AB/2) and secondary inversion TEM data from ATDEM project in A.D. 2012 of "Department of Ground Water Resources" with 5 flight lines as shown in figure 4-3for classified soil and/or rock layers. The study is designed to carry out vertical electrical sounding (VES) geophysical survey into 81 points, 79points of which are in the study area and 2 points of which are outside the area. The data for the latter 2 points are collected for comparison and interpretation purpose in soil open pit (80^{th} point) and well-logging location (81^{th} point) as shown in figure 4-1. The inversion result will be shown in apparent resistivity fitting curve and cross section from Line1 to Line6 (Figure 4-2). The interpretation procedure will rely both on field survey data and well-logging data with geophysical data. The results are presented below;

4.1 Well-logging and geophysical data comparison

Nearby study area has a drilling well of ATDEM project (DGR, 2012) that are applied wireline-logging and the rock samples from the well were collected in cutting sample, which is in UTM grid 549696E, 1813719N. The drilling well is located approximately 400 meters in the north of the study area, which has VES geophysical survey 81^{th} point (VES-Loggingwell) for comparison and interpretation purpose. The inversion result is shown in table 4.1-1 and the comparison with TEM inversion data, wireline-logging data, and cutting sample data are shown in table 4.1-2.

Table 4.1-1. "VES-Loggingwell" apparent resistivity curve and inversion result.

Apparent resistivity curve	Layer	ρ (Ωm)	Thickness (m.)	bottom depth (m.)
	1	78.7	0.30	0.30
	2	320	0.95	1.25
	3	2.44	0.24	1.49
	4	749	1.25	2.74
	5	22	5.26	8.00
	6	374		

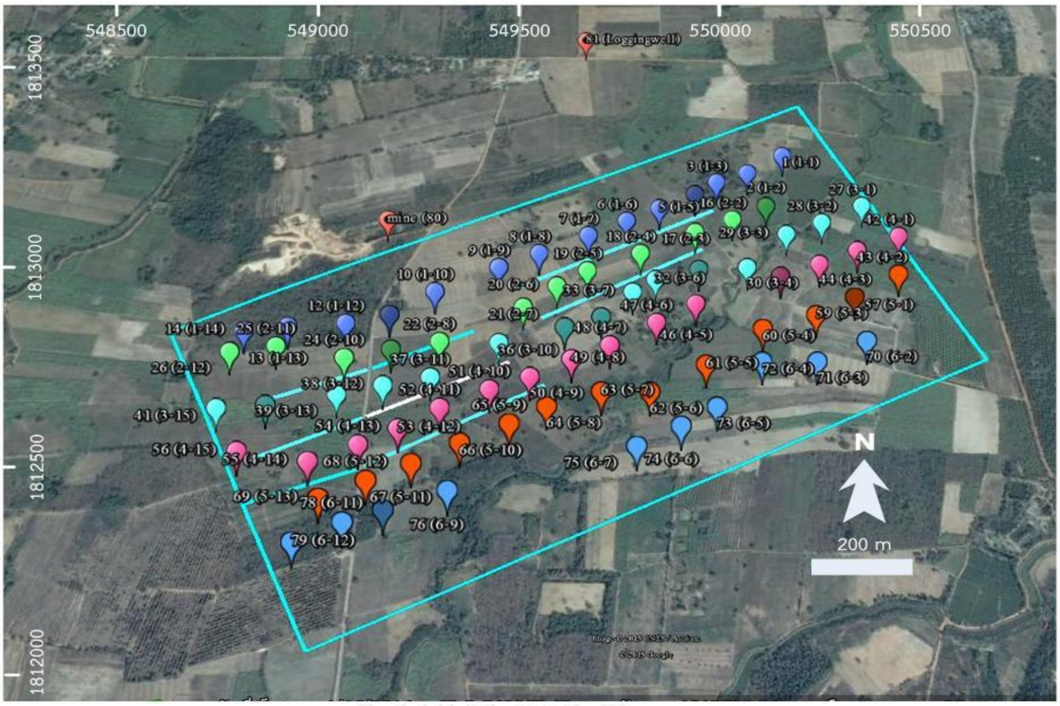


Figure 4-1. 81 vertical electrical sounding points and 2D multi-electrode line (white line) in study area (white frame).

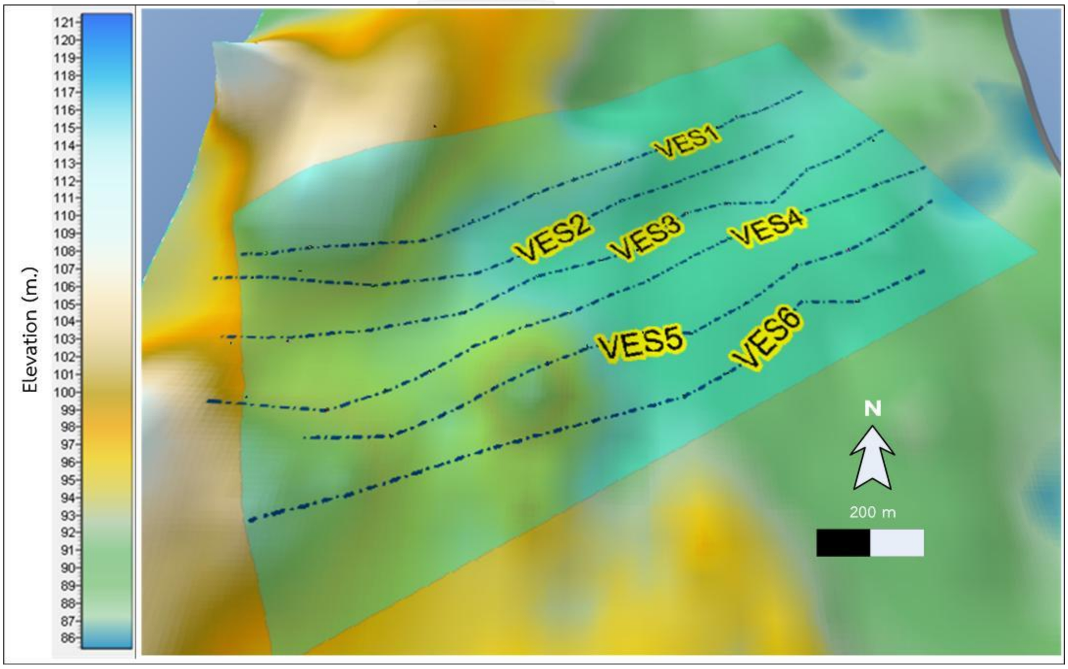


Figure 4-2. 6 vertical electrical sounding section lines and area elevation.

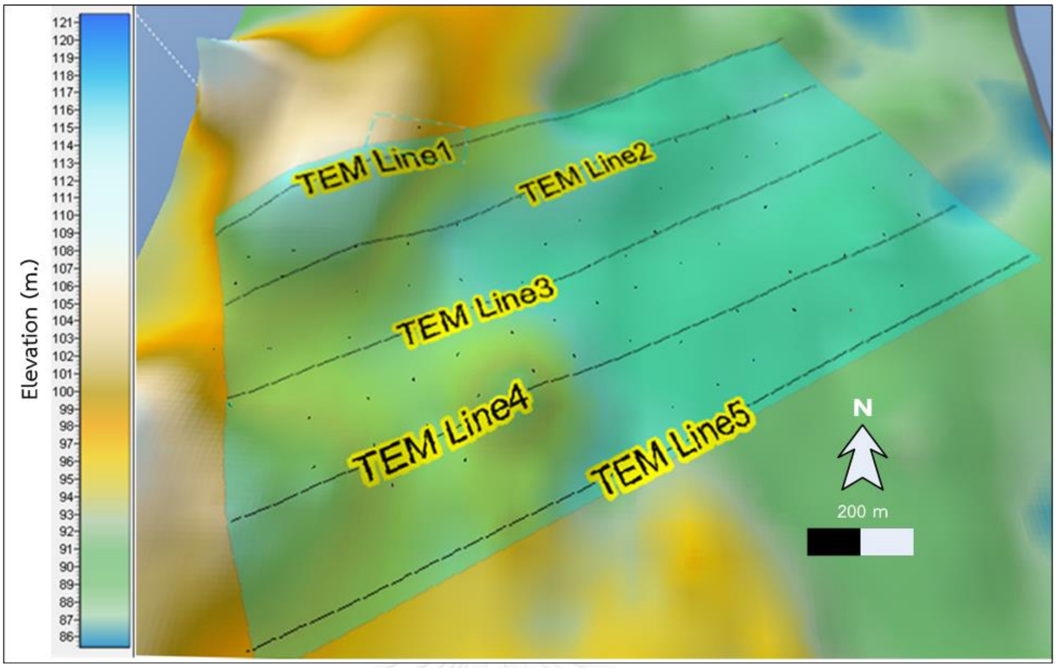


Figure 4-3. 5 airborne TEM lines and area elevation.

Figure 4-4. Soil pit figures locations.

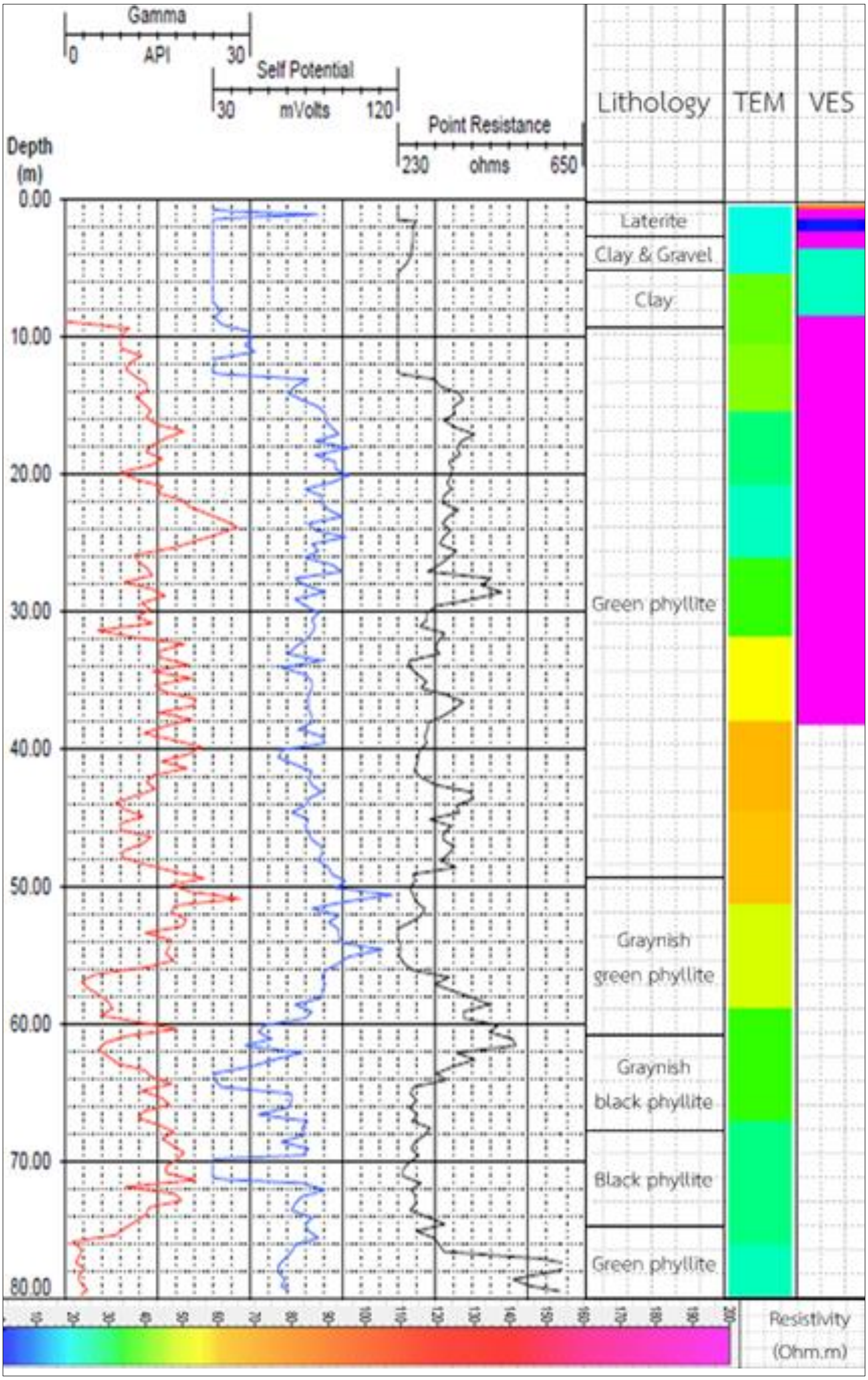


Figure 4-5. Comparison of wireline-logging consisting of gamma ray, self-potential, and point resistance; lithological logging; TEM; and VES data.

Figure 4-5 shows the comparison of wireline logging data, lithological logging data, TEM data, and VES data. The result presents that VES resistivity value quite corresponds with to wireline-logging and lithological logging data. VES Inversion result shows that laterite layer is 2.74 meters thick with resistivity value of more than 200 ohm.m. The next lower layer is clay and clay & gravel with 5.26 meters of thickness in total and has resistivity value range between 20 – 30 ohm.m. The fresh phyllite layer is the bedrock occurring in 8 meters depth below the surface and has resistivity value more than 200 ohm.m. The resistivity values depend on clay content, moisture, and degree of weathering.

However, TEM resistivity values are rather different from reality. The TEM resistivity values in fresh phyllite are lower than expected. The inversion result shows topsoil consisting of laterite and clay, which is approximately 6 meters thick and has resistivity range between 20 – 30 ohm.m, and fresh phyllite bedrock, which is 6 meters depth from the surface and has resistivity from 45 ohm.m onwards. Because TEM has limited capabilities to classify high resistivity layer of rock or soil. The response curve of dissimilar model are insignificantly separated if resistivity value is over 80 ohm.m (Auken, 2003), causing inaccurate interpretations. Moreover, TEM data have a chance to be affected by noises such as electric post, building, or some types of land cover more than DC resistivity ground survey.

Although, TEM resistivity inversion values are rather different from reality, but the interpretation procedure can use these values as an advantage to make a comparison and correlation of rock or soil layers in areas where data are lacking because TEM data have quite detailed retention period with its sounding point spacing only of 20 meters and quite high penetration depth, which can compensate for limitation of VES ground survey that it cannot survey some area such as dense forest or swamp and has limitation of sounding point quantity and wide spacing of approximately 100 meters.

Furthermore, the wireline-logging result shows low value gamma ray and high electric resistance zone, indicating low quantity of clay contents and rather fresher rocks than other zones such as 56 – 62 and 76 - 80 meters depth rock layers, which possibly have quartz vein intrusive as shown in figure 4.1-1 and 4.1-2.

Figure 4.1-1. Large quartz vein in soil pit at UTM grid **549212**E, 1813133N aligns in 336°/74° is 1.2 – 1.5 meters thick.

Figure 4.1-2. Quartz vein is 10 centimeters maximum thick in soil pit at UTM grid **549**244E, 1813154N intrude in phyllite layer.

4.2 Soil pit section and geophysical data comparison

The northwest of study area has soil pit. This research adopts VES resistivity technique for survey 80th point (VES-mine) at UTM Grid 549268E, 1813107N (table 4.2-1) for interpretation and the comparison results are illustrated in figure 4.2-1

Table 4.2-1 “VES-Mine” apparent resistivity curve and inversion result.

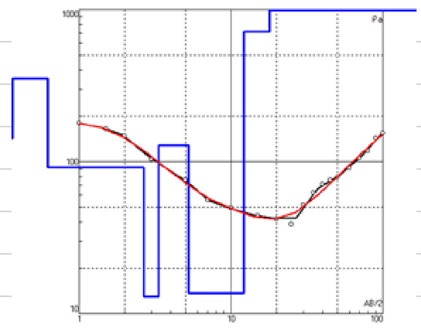
Apparent resistivity curve	Layer	ρ (Ωm)	Thickness (m.)	bottom depth (m.)
	1	143	0.32	0.32
	2	351	0.29	0.61
	3	92.1	2.03	2.64
	4	12.9	0.68	3.32
	5	128	1.91	5.23
	6	13.6	6.87	12.10
	7	720	5.81	17.91
	8	1779		

Figure 4.2-1 shows comparison of soil pit cross-section, TEM inversion data, and VES inversion data. The VES inversion results present that lateritic topsoil consists of gravel and sand, which has resistivity range in 90 – 350 ohm.m. The next lower layer is weathered phyllite and has approximately 9 meters thickness which has resistivity range between 10 – 130 ohm.m depending on the degree of weathering, moisture of soil/rock layer, and quantity of clay contents. The bottom or bedrock is fresh phyllite that is 12.1 meters depth below from the ground surface, which has resistivity more than 300 ohm.m

The TEM inversion result (*1) shows insignificant difference and high error in high resistivity layer, making it difficult to classify high resistivity lateritic topsoil and thick weathered phyllite. Moreover, TEM resistivity values in fresh phyllite is lower than reality. TEM inversion result shows topsoil is approximately 4 meters thick, and the next lower layer is weathered phyllite having similar resistivity value to topsoil between 40 – 80 ohm.m.

(*1) TEM inversion data does not belong to this location, but the sounding point of TEM Line1 which is the nearest data point in 40 meters distance from soil section.

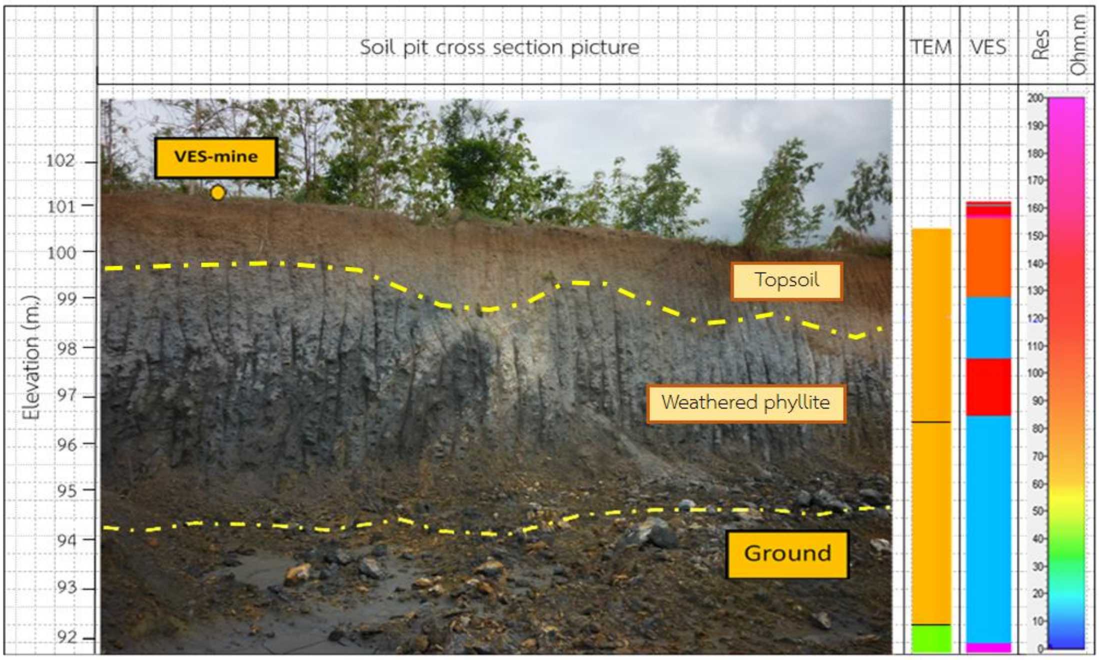


Figure 4.2-1. VES-mine point and comparison of soil pit cross section picture, TEM, and VES data.

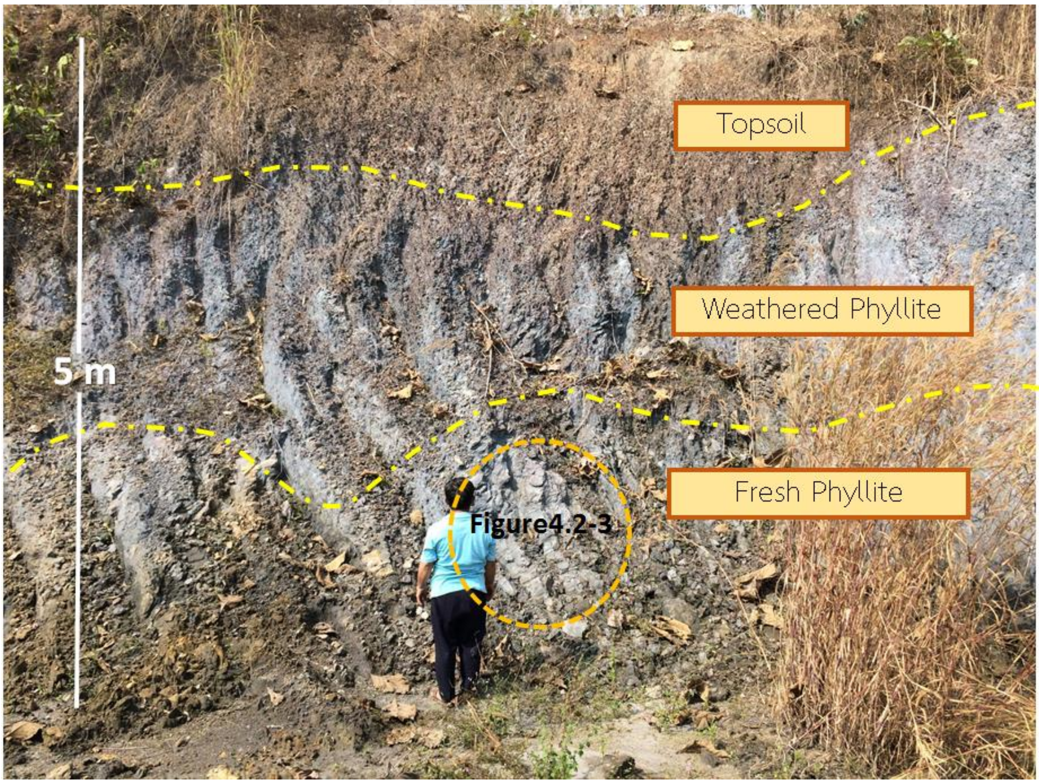


Figure 4.2-2. Soil pit cross section at UTM Grid 549110E, 1813129N

Figure 4.2-3. Fresh phyllite at UTM Grid 549110E, 1813129N

Figure 4.2-2 and Figure 4.2-3 show soil pit cross section at UTM 549110E, 1813129N. The top layer is sand and gravel lateritic topsoil and the lower layer is weathered phyllite. The next lower layer is greyish-green fresh phyllite which is approximately 2.5 – 4 meter below the surface. Figure 4.2-4 and Figure 4.2-5 illustrate weathered phyllites in soil pit that has various degree of weathering. Some high weathered phyllites are weathered into clay and gravel sediment.

Figure 4.2-4. Weathered phyllite at UTM Grid 549156E, 1813117N

Figure 4.2-5. Soil pit cross section at UTM Grid 549032E, 1813005N

Figure 4.2-2 and Figure 4.2-6 show geological structure having significant changes in the area nearby. Figure 4.2-2 illustrates shallow fresh phyllite, on the other hand, figure 4.2-6 does not show fresh phyllite in 5 meters depth from surface, which has topsoil of 2 – 3 meters thickness, and the next lower layer is high weathered phyllite weathered into clay and gravel in some areas. Rocks were highly weathered in weak zones such as fracture or crack zone that make water to permeate and scour.

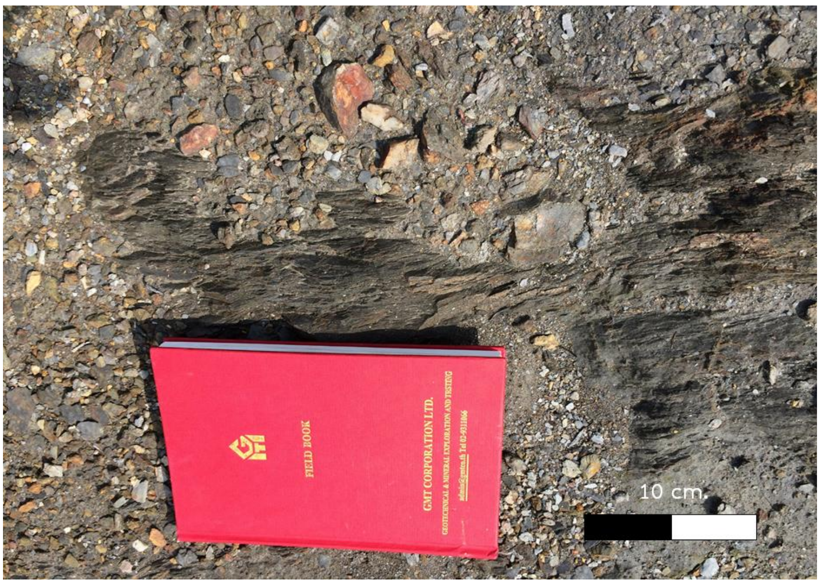


Figure 4.2-6. Weathered phyllite at UTM Grid 549062E, 1813089N

4.3 Time-domain data interpretation

The study area consists of 5 TEM geophysical survey flight lines which are secondary data from ATDEM project (DGR, 2012). The flight lines are shown in figure 4-3 with 20-meter sounding point spacing approximately. The results help classify rock units by resistivity values from TEM data inversion (*2) which are shown in figure 4.3-1. The cross-section including data interpretation is also presented below as well;

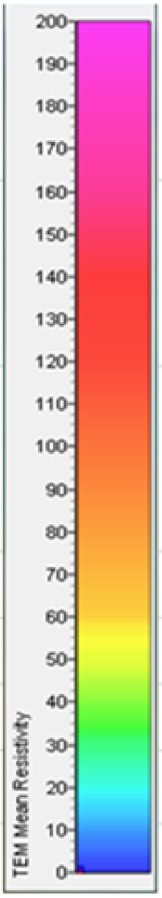
<table>
<tr><th>ρ (Ohm.m)</th><th>Degree of weathering</th><th>Rock unit</th></tr>
<tr><td rowspan="7">
</td><td rowspan="3">Fresh rock</td><td>Fresh phyllite</td></tr>
<tr><td>Laterite,Lateritic soil, Unsaturated soil</td></tr>
<tr><td>quartz vein</td></tr>
<tr><td rowspan="3">Moderated weathered rock</td><td>Moderated weathered phyllite</td></tr>
<tr><td>Clayey sand</td></tr>
<tr><td>Gravel and clay</td></tr>
<tr><td>High weathered rock</td><td>High weathered phyllite, Clay</td></tr>
</table>

Figure 4.3-1. Resistivity value from TEM data inversion including data interpretation in degree of weathering and rock units' form.

(*2) TEM data inversion results of high resistivity layer is subject to high error chance (lower than reality). The above table shows the results which are already compared with well-logging and pit cross section for correlation in the next procedure. Presented resistivity values of some areas do not reflect the area actual resistivity.

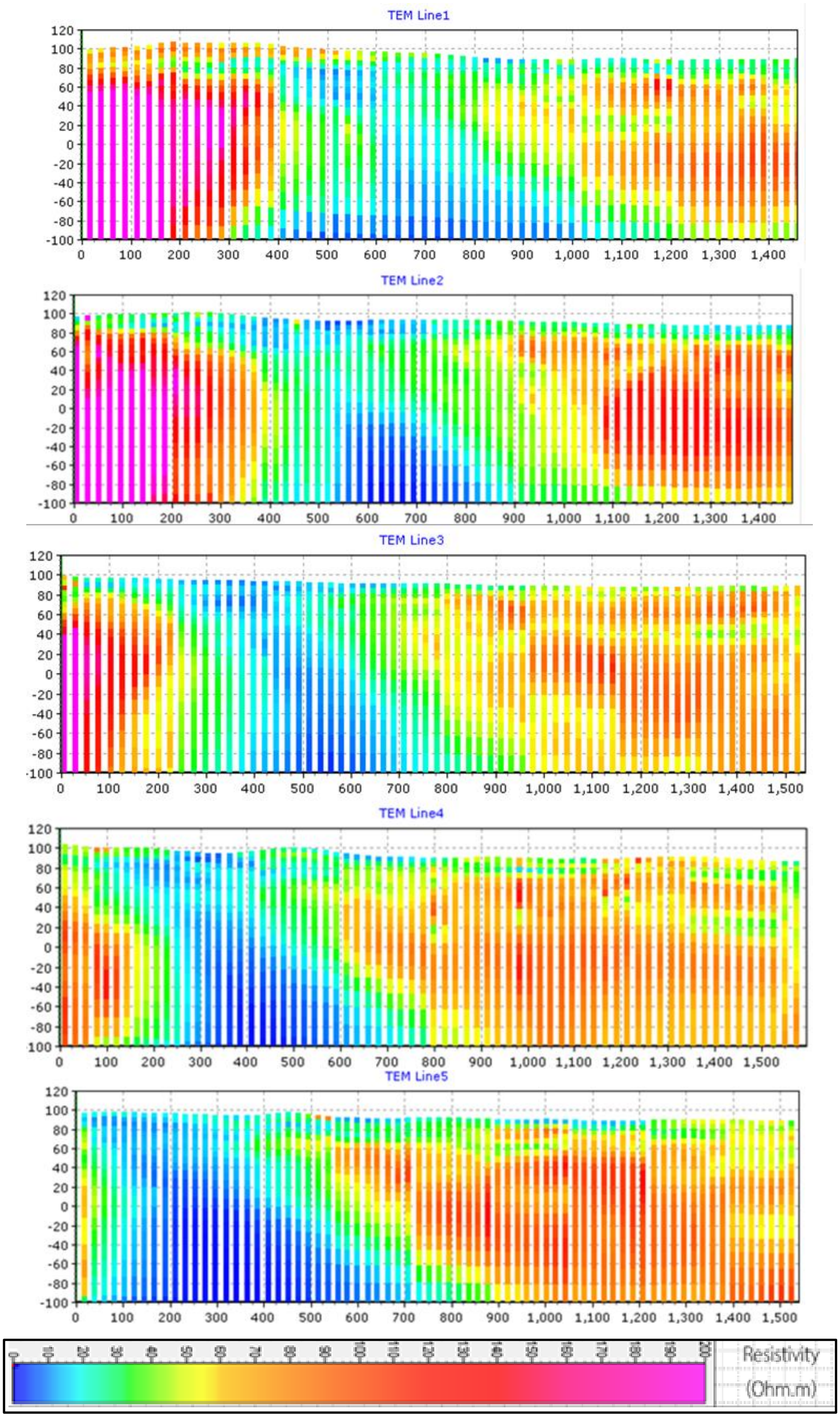


Figure 4.3-2. Inversion result of TEM line1 – line 5 and resistivity scale (ohm.m)

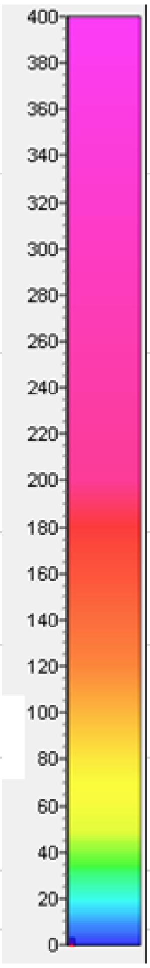
Figure 4.3-2 shows time-domain electromagnetic 1D sounding cross section of TEM line1 to line 5. These section is 1,600 meters in total length in the northeast – southwest direction and the spacing between line surveys are approximately 200 meters interval. TEM cross sections present topsoil thickness of 0.5 – 15 meters with range between 5 – 50 ohm.m depending on soil type, clay mineral contents and moisture. Low resistivity topsoil is toward to the left side of TEM survey lines overlie significant weak zone that presented in dark blue – light blue. Most of topsoil are gravelly clay sediment and some “gravel and sand” is occurred some area.

In addition, high resistivity zones that present in dark orange – purple presented below are approximately 10 – 20 meters from surface, are phyllite or phyletic shale zone. The TEM resistivity values show phyllite in the left side of these section (west zone of study areas are almost present in dark red - purple) are fresher and denser than the right side of these section (east zone of study areas are almost present in orange - red) which are indicated fracture or/and crack in the west zones are less than the east zone and less groundwater potential. According to these TEM section, the east zone show many weak zones that are weathered phyllite or/and minor fractures in phyllite present in yellow or light orange inside dark orange – red mass zone (fresh phyllite). These some weak zones could be groundwater potential expected location of the study area.

Furthermore, the study area has significant weak zones which are presented in dark blue – blue mass zones below the surface that are showed in TEM cross section from the middle of TEM line1 slightly toward to left side of TEM line5. According to TEM resistivity cross section, these significant weak zones, which align in northern – southern direction and dip to west side, are mass weathered phyllite or phyletic shale or/and major fractures zones and could be strike slip fault, which are the most groundwater potential zone in consolidated rock aquifer of the study area.

4.4 VES data inversion and interpretation

The study area consists of 79 vertical electrical sounding points and other 2 points at logging well and soil pit, which are divided into 6 survey lines. These are shown in figure 4-2. Most of them have 100 meter distance sounding point spacing, however, some of the points have less or more distance depending on whether or not the area can be explored and facilitates the use of electrical cables. VES data inversion results can classify rock units from resistivity value as shown in figure 4.4-1. Inversion results and their interpretations of 6 survey lines are provided below;



ρ (Ohm.m)	Degree of weathering	Rock unit
	Fresh rock	Fresh phyllite
		Laterite,Lateritic soil, Unsaturated soil
		quartz vein
	Moderated weathered rock	Moderated weathered phyllite
		Clayey sand
		Gravel and clay
	High weathered rock	High weathered phyllite, Clay

Figure 4.4-1. Resistivity value from VES inversion including data interpretation in degree of weathering and rock unit forms.

4.4.1 VES Line 1 –consists of 14 sounding points which are labeled as 1st point – 14th point having approximately 1,400 meters in total length in the northeast – southwest direction. The results are shown in appendix.

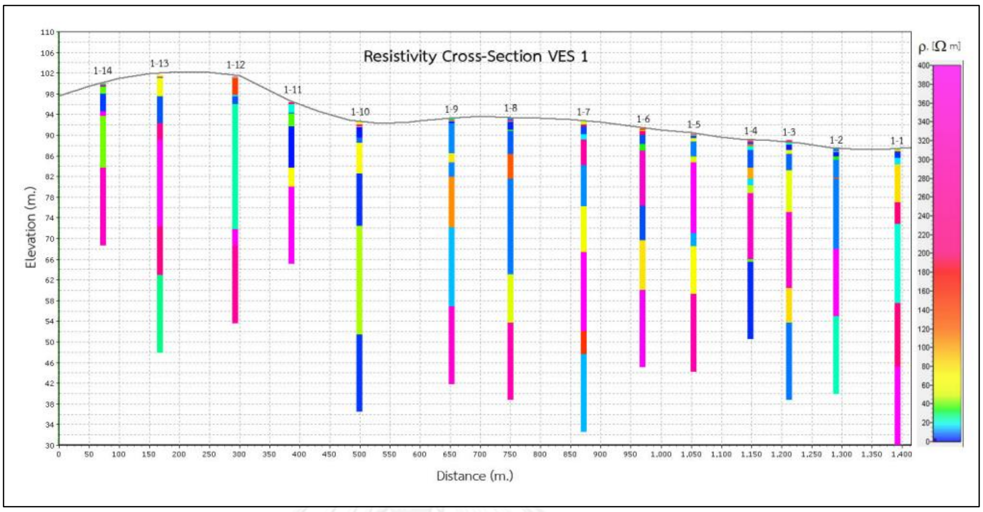


Figure 4.4.1-1. VES Line 1 cross-section and resistivity values.

Figure 4.4.1-1 shows VES Line 1 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Laterites are found in VES1-7, VES1-11, and VES 1-12 sounding points are 0 – 1.5 meter depth from the surface. Most of the top fresh bedrocks are occurred approximately 5 – 10 meters from the surface below and are discovered in weak zones at VES1-10 sounding point that corresponds with TEM interpretation results. Interbedded high weathered phyllite with moderated weathered phyllite are occurred approximately 5 meters from the surface and no fresh phyllite is discovered from the surface to 70 meters depth.

4.4.2 VES Line 2 – consists of 12 sounding points labeled as 15st point – 26th point which are approximately 1,300 meters in total length in the northeast – southwest direction. The results are shown in appendix.

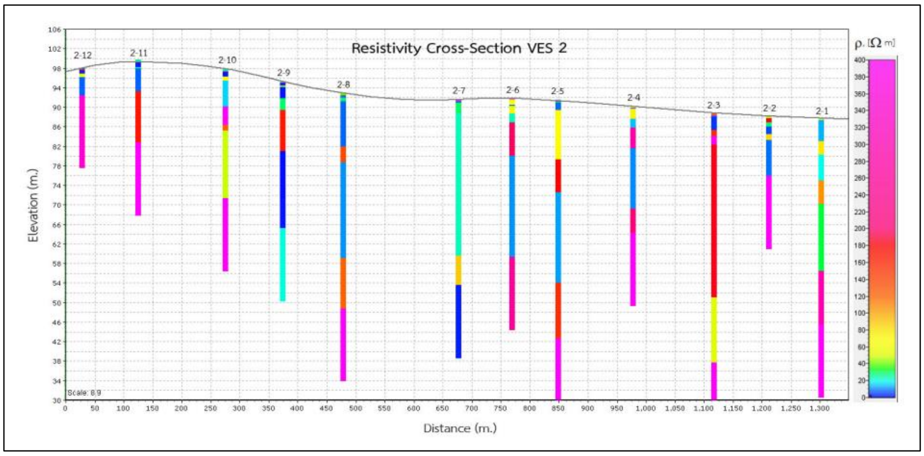


Figure 4.4.2-1. VES Line 2 cross-section and resistivity values.

Figure 4.4.2-1 shows VES Line 2 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Laterites are not found in this section. Most of the top fresh bedrocks are occurred 10 meters depth or more below the surface and are discovered weak zones at VES2-9 sounding point that corresponds with TEM interpretation results. Interbedded high weathered with moderated weathered phyllite are occurred approximately 3 meters from the surface and no fresh phyllite is discovered from the surface to 60 meters depth.

4.4.3 VES Line 3 – consists of 15 sounding points labeled as 27st point – 41th point which is approximately 1,550 meters in total length in the northeast – southwest direction. The results are shown in appendix.

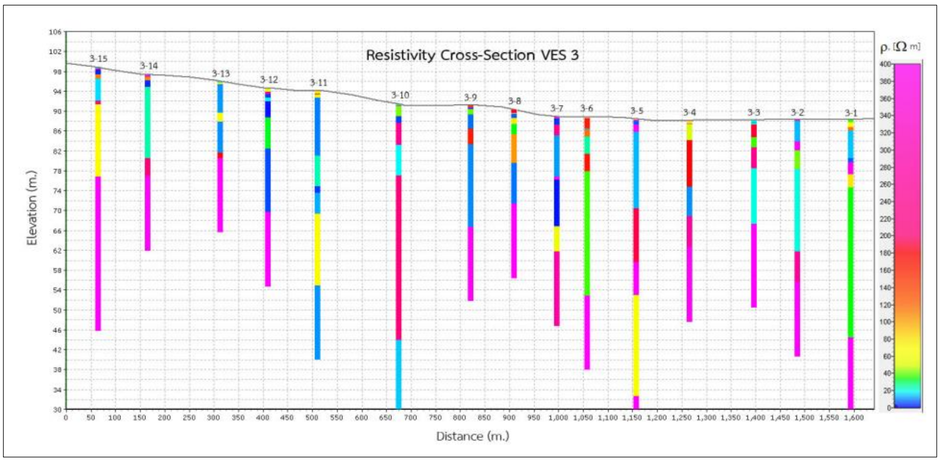


Figure 4.4.3-1. VES Line 3 cross-section and resistivity values.

Figure 4.4.3-1 shows VES Line 3 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Possible Laterites layers are found in VES3-2, and VES3-3 sounding points (Figure 4.3-2) which are 2 – 5 meters depth from surface. Most of the top fresh bedrocks are occurred approximately 5 – 30 meters depth from the surface and are discovered in weak zones at VES3-11 sounding point that corresponds with TEM interpretation results. Interbedded high weathered phyllite with moderated weathered phyllite are occurred approximately 2 meters from the surface and no fresh phyllite is discovered from the surface to 60 meters depth.

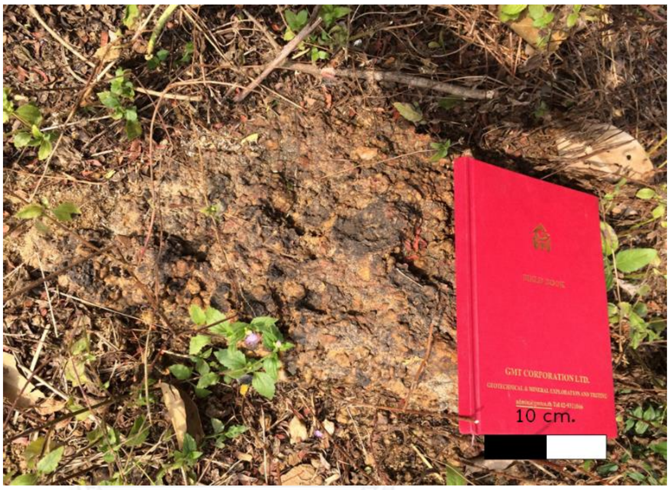


Figure 4.4.3-2 Laterite emerging from ground at UTM Grid 550196E, 1813155N

Figure 4.4.3-3. Laterite emerging from ground at UTMGrid 550303E, 1813130N

4.4.4 VES Line 4 – consists of 15 sounding points labeled as 42st point – 56th point which is approximately 1,550 meters in total length in the northeast – southwest direction. The results are shown in appendix.

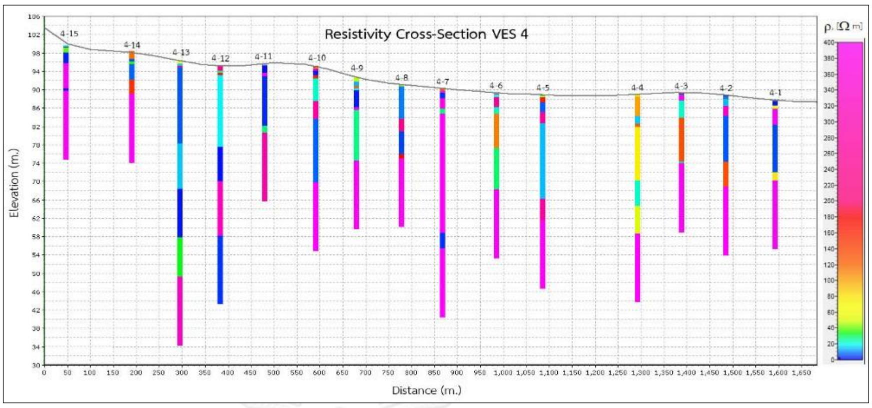


Figure 4.4.4-1. VES Line 4 cross-section and resistivity values.

Figure 4.4.4-1 shows VES Line4 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Possible Laterites layers are found in VES4-1, VES4-2, VES4-3, VES4-6, VES4-7 and VES 4-11 sounding points which are 2-4 meters depth from the surface. Most of the top fresh bedrocks are occurred approximately 5 – 40 meters depth from the surface.

4.4.5 VES Line 5 – consists of 13 sounding points labeled as 57st point – 69th point which is approximately 1,400 meters in total length in the northeast – southwest direction. The results are shown in appendix.

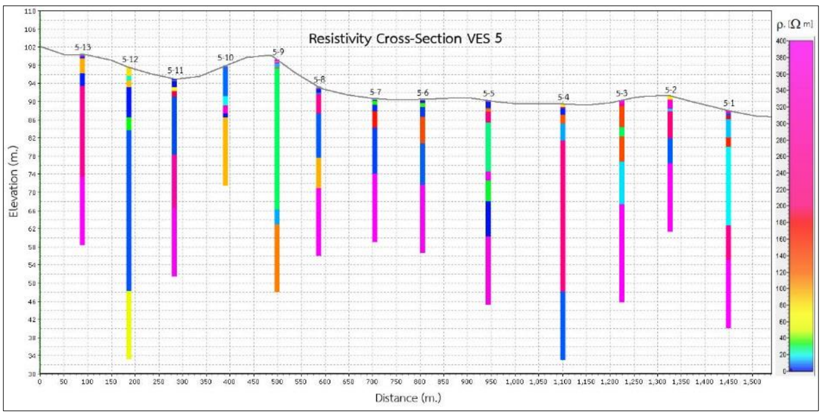


Figure 4.4.5-1. VES Line 5 cross-section and resistivity values.

Figure 4.4.5-1 shows VES Line5 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Possible Laterites layers are found in VES5-2, VES5-3, and VES 5.9 sounding points which are 0 – 2 meter depth from surface. Most of the top fresh bedrocks are occurred approximately 4 – 50 meters depth from the surface and are discovered in weak zones at VES5-9 and VES 5-12 sounding point that corresponds with TEM interpretation results. Interbedded high weathered phyllite with moderated weathered phyllite are occurred approximately 2 - 3 meters from the surface and no fresh phyllite is discovered from the surface to 70 meters depth.

4.4.6 VES Line 6 – consists of 10 sounding points labeled as 70st point – 79th point which is approximately 1,300 meters in total length in the northeast – southwest direction. The results are shown in appendix.

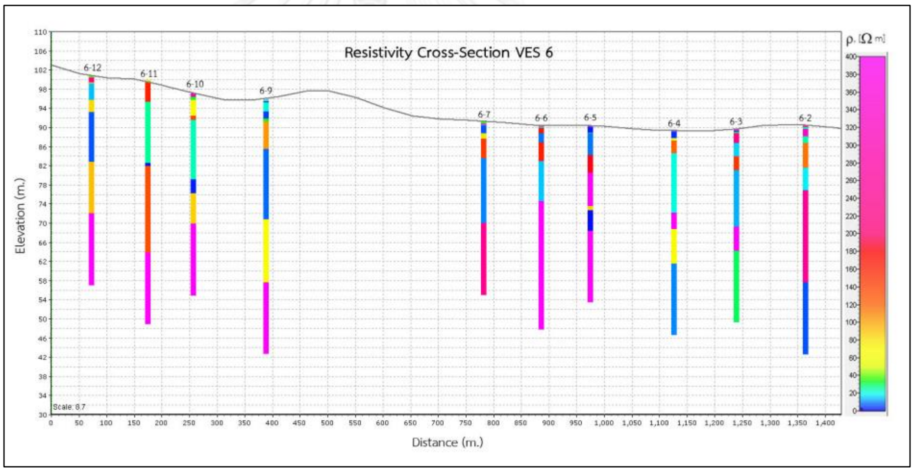


Figure 4.4.6-1. VES Line 6 cross-section and resistivity values.

Figure 4.4.6-1 shows VES Line6 cross section. Topsoil resistivity depends on clay content, moisture, and soil type. Possible Laterites layer are found in VES6-2, VES6-3, and VES 6-12 sounding points which are 0 – 1.5 meters depth from surface. Most of the top fresh bedrocks are occurred approximately 12 – 60 meters from the surface. High weathered zone and deep fresh bedrocks are found at VES6-9, VES6-10, and VES 6-11. Fresh rocks are discovered at depth of 50 meters and below.

4.5 2D Multi-electrode data interpretation

The study area consists of 8 2D multi-electrode survey lines. Line1 is 505 meters in length, line2 is 415 meters in length, line3-1 is 235 meters in length, line3-2 is 235 meters in length, line4-1 is 235 meters in length, line4-2 is 325 meters in length, line5-1 is 235 meters in length, and line5-2 is 415 meters in length. They are presented in figure 4.5-1 and are approximately 2,600 meters in total length and 5 meters distance electrode spacing. The topsoil results are rather different from VES technique because this 2D multi-electrode technique survey different period season. VES technique is used in early June which is in the rainy season, most of the topsoil is therefore saturated. On the other hand, 2D multi-electrode technique is used in December, a month in the winter season when topsoil is rather dry and unsaturated. These lead to different resistivity values. However, sub surface zone that is saturated and has some moisture takes no effect from this condition, therefore, no difference in resistivity values are observed. In addition, this research has limitations in terms of time, budget, and inaccessible area, therefore, the 2D multi-electrode lines are designed to survey accessible significant anomaly zones where potential aquifers are expected. The results and their interpretations are presented below;

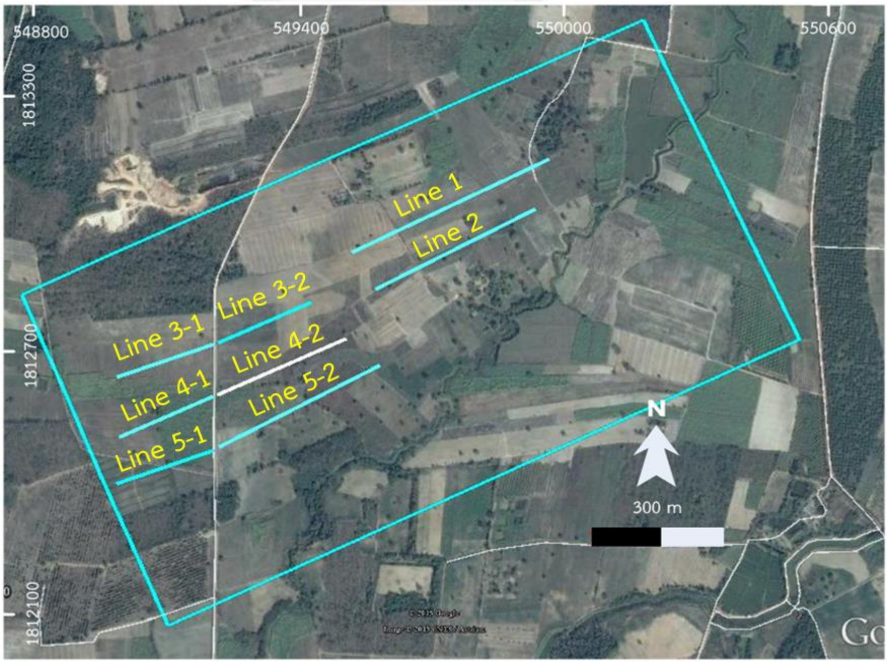


Figure 4.5-1. 2D-multi electrode survey lines in study area.

(1) **2D Line 1** – This line is 505 meters in total length in the northeast – southwest direction as shown in figure 4.5-2. 2D resistivity cross-section presents lateritic topsoil thickness of 3 – 5 meters with resistivity range between 15 – 300 ohm.m depending on soil types, clay mineral contents and moisture. The line left end shows low resistivity zone near the surface which is clay and/or gravelly clay topsoil sediment, and the other high resistivity topsoil zones are laterite or unsaturated clayey sand or/and sand and gravel. Topsoils are underlain by high weathered phyllite or/and saturated clay sediment layer with resistivity range between 1 – 30 ohm.m that is presented in dark blue – light greenish blue. The red – purple zones shown below are approximately 6 – 12 meters from the surface, which are fresh phyllite having some weak zones that presented in light blue - green such as fracture, fault zones or/and weathered phyllites that have various degree of weathering and present different resistivity values, indicating potential aquifers depending on fracture connection, weathered zone thickness, and degree of weathering. The higher degree of weathering, the lower resistivity.

(2) **2D Line 2** – This line is 415 meters in total length in the northeast – southwest direction as shown in figure 4.5-3. 2D resistivity cross-section presents lateritic topsoil thickness of 2 – 5 meters with resistivity range between 100 – 300 ohm.m depending on soil types, clay mineral contents and moisture. Most of the topsoils are sand and gravel sediment which are underlain by moderated – high weathered phyllite layer with resistivity range between 1 – 30 ohm.m that is presented in dark blue – yellowish green. The red–purple zones shown below are approximately 3 – 8 meters from the surface, which are fresh phyllite having some weak zones that presented in light blue - green such as fracture, fault zones or/and weathered phyllites that have various degree of weathering and present different resistivity values, indicating potential aquifers depending on fracture/fault zone connection, weathered zone thickness, and degree of weathering. The higher degree of weathering, the lower resistivity value. Line 2 degree of weathering zone follows similar trend and characteristic when compared with Line1, and some fractures or/and weathered zones which are connected can be potential aquifers.

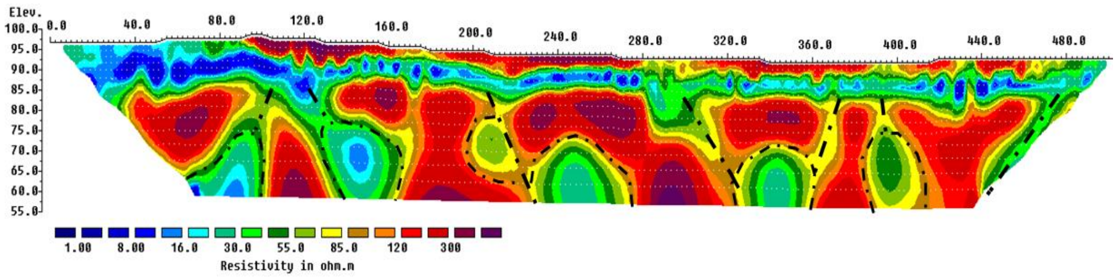


Figure 4.5-2. 2D multi-electrode resistivity cross-section of Line 1. Black dot lines present phyllite weak zones that have high degree of weathering rock or/and fracture or fault zone, which shows high possibility of potential aquifers.

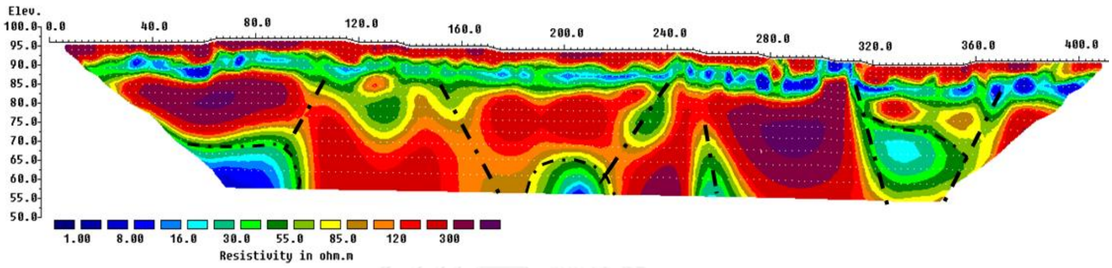


Figure 4.5-3. 2D multi-electrode resistivity cross-section of Line 2. Black dot lines present phyllite weak zones that have high degree of weathering rock or/and fracture or fault zone, which shows high possibility of potential aquifers.

(3) **2D Line 3-1 -** This line is 235 meters in total length in the northeast – southwest direction as shown in figure 4.5-4. 2D resistivity cross-section presents lateritic topsoil thickness of 1 – 3 meters with resistivity range between 10 – 60 ohm.m depending on soil types, clay mineral contents and moisture. Most of the topsoils are low resistivity layer, gravelly clay sediments which are underlain by high weathered phyllite or/and saturated clay sediment layer with resistivity range between 5 – 30 ohm.m that is presented in dark blue – light green blue. The red–purple zones shown below are approximately 5 – 15 meters from the surface, which are dense fresh phyllites having few fractures or/and weathered zone that is showed as black dot line. The dense fresh phyllites overlie moderated weathered phyllite in horizontal position parallel to the surface is presented in yellowish green – orange.

(4) 2D Line 3-2 - This line is 235 meters in total length in the northeast – southwest direction as shown in figure 4.5-5. 2D resistivity cross-section presents lateritic topsoil thickness of 1 – 5 meters with resistivity range between 5 – 60 ohm.m depending on soil types, clay mineral contents and moisture. Most of the topsoils are underlain by high weathered phyllite or/and saturated clay sediment layer with resistivity range between 2 – 30 ohm.m that is presented in dark blue – light green blue in "1-500 ohm.m scale bar". Line 3-2 section crosses through the significant weak zone in blue (low resistivity zone) in TEM data interpretation of the study area. The fresh rock zone, which is presented below from the surface approximately 15 meters, is shown between 50 - 80 meters from the line left end. Most of the areas, which have low resistivity values with resistivity range between 5 – 60 ohm.m, are considered as weak zones. The weak zones consist of thick high weathered phyllite and/or fracture and/or fault zone, and some moderated weathered phyllites which could be the main trend fractures of this area can be potential aquifers.

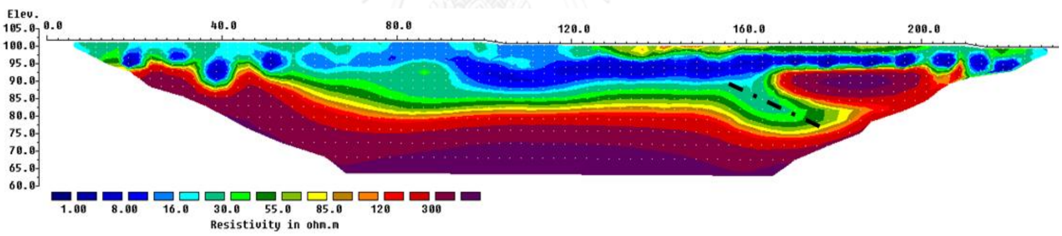


Figure 4.5-4. 2D multi-electrode resistivity cross-section of Line 3-1 and black dot lines present phyllite weak zones.

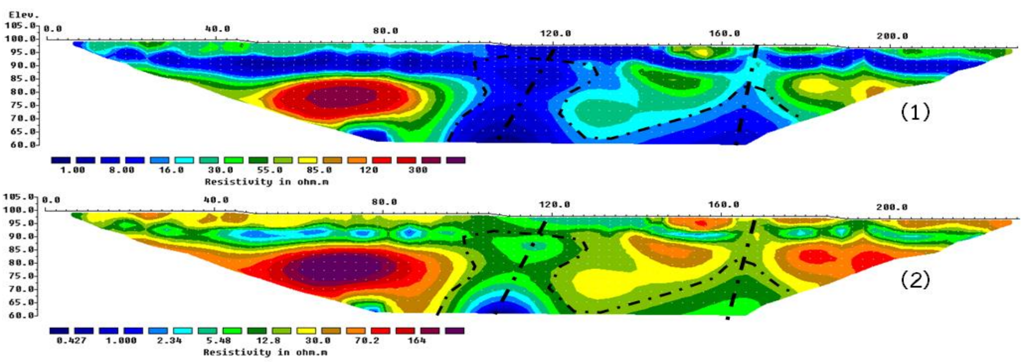


Figure 4.5-5. 2D multi-electrode resistivity cross-section of Line 3-2 in 2 different scale bars; (1) presents in 1 – 500 ohm.m resistivity scale bar, (2) present in logarithm resistivity scale bar.

(5) **2D Line 4-1 -** This line is 235 meters in total length in the northeast – southwest direction as shown in figure 4.5-6. 2D resistivity cross-section presents lateritic topsoil thickness of 0.5 – 8 meters with resistivity range between 15 – 80 ohm.m depending on soil types, clay mineral contents and moisture. Most of the topsoils are low resistivity layer which is gravelly clay sediment and some clayey sand near the line right zone. Line 4-1 characteristic and structure are similar to line3-1. The red – purple zones, which shown below are approximately 8 – 15 meters from the surface, are dense fresh phyllite having few fractures or/and weathered zone that is showed as black dot line. The dense fresh phyllites overlie moderated weathered phyllite in horizontal position parallel to the surface is presented in yellowish green – orange.

(6) **2D Line 4-2 -** This line is 325 meters in total length in the northeast – southwest direction as shown in figure 4.5-7. 2D resistivity cross-section presents lateritic topsoil thickness of 1 – 5 meters with resistivity range between 5 – 20 ohm.m depending on soil types, clay mineral contents and moisture. The topsoils are underlain by high weathered phyllite or/and saturated clay sediment layer with resistivity range between 5 – 20 ohm.m that is presented in dark blue – light greenish blue. Line 4-2 section crosses through the significant weak zone in blue (low resistivity zone) in TEM data interpretation of the study area. The fresh rock zone, which is presented below from the surface approximately 15 - 30 meters, is shown between 120 - 260 meters from the line left end**.** More than half of the areas, which have low resistivity values with resistivity range between 5 – 40 ohm.m, are considered as weak zones. The weak zones consist of thick high weathered phyllite and/or fracture and/or fault zone. Left zone of the line4-2, which is more weathered than other zones showing thick weathered rock or/and fracture zones, is approximately 30 – 40 meters thick, and could be the main trend fractures of this area can be potential aquifers.

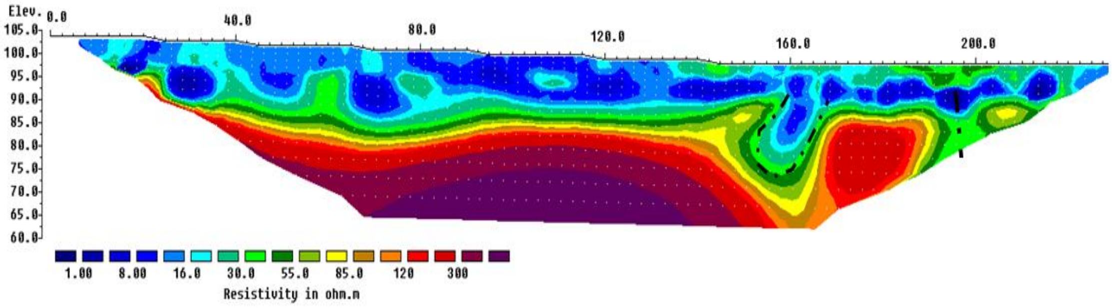


Figure 4.5-6. 2D multi-electrode resistivity cross-section of Line 4-1 and black dot lines present phyllite weak zones.

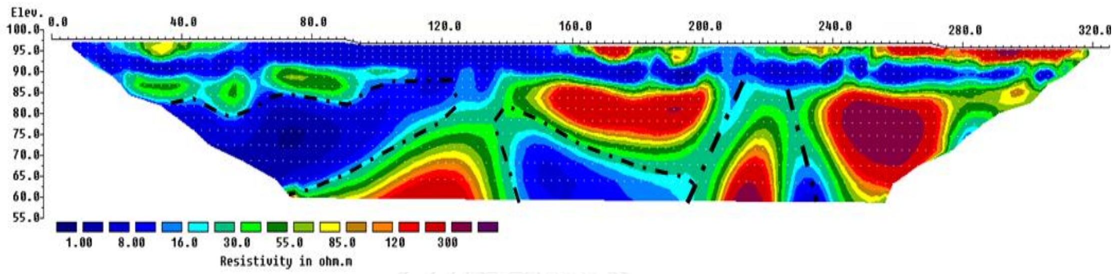


Figure 4.5-7. 2D multi-electrode resistivity cross-section of Line 4-2 and black dot lines present phyllite weak zones.

(7) 2D Line 5-1 - This line is 235 meters in total length in the northeast – southwest direction as shown in figure 4.5-8. 2D resistivity cross-section presents lateritic topsoil thickness of 1 – 10 meters with resistivity range between 15 – 300 ohm.m depending on soil types, clay mineral contents and moisture. Topsoil, which is high resistivity unsaturated “gravel and sand” sediments and laterite layer are 5 – 7 meters thick presented in orange – red; and other is “clay and gravel” or “sandy clay” is presented in light blue – green, is underlain by high weathered phyllite or saturated clay sediment layer with resistivity range between 5 – 25 ohm.m that is presented in dark blue – light greenish blue. The red – purple zones, which shown below are approximately 10 – 35 meters from the surface, are dense fresh phyllite having few fractures or/and weathered zone that is showed as black dot line. The dense fresh phyllites overlie moderated weathered phyllite in horizontal position parallel to the surface is presented in yellowish green – orange.

(8) **2D Line 5-2 -** This line is 415 meters in total length in the northeast – southwest direction as shown in figure 4.5-9. 2D resistivity cross-section presents lateritic topsoil thickness of 1 – 9 meters with resistivity range between 15 – 300 ohm.m depending on soil types, clay mineral contents and moisture. Topsoil, which is high resistivity unsaturated “gravel and sand” sediments and laterite layer are 4 – 7 meters thick presented in orange – reddish purple; and other is “clay and gravel” or “sandy clay” is presented in light blue – green, is underlain by high weathered phyllite or saturated clay sediment layer with resistivity range between 5 – 30 ohm.m that is presented in dark blue – light greenish blue. The red – purple zones shown below are approximately 9 – 30 meters from the surface, which is fresh phyllite having some weak zones such as fracture, fault zone or/and weathered phyllite. Weathered phyllite have various degree of weathering and present different resistivity values, which can be potential aquifers depending on fracture zone connection, weathered zone thickness, and degree of weathering. The higher degree of weathering, the lower resistivity value.

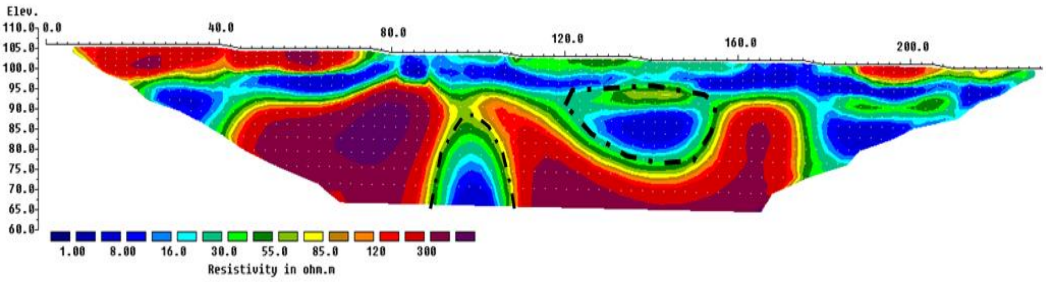


Figure 4.5-8. 2D multi-electrode resistivity cross-section of Line 5-1 and black dot lines present phyllite weak zones.

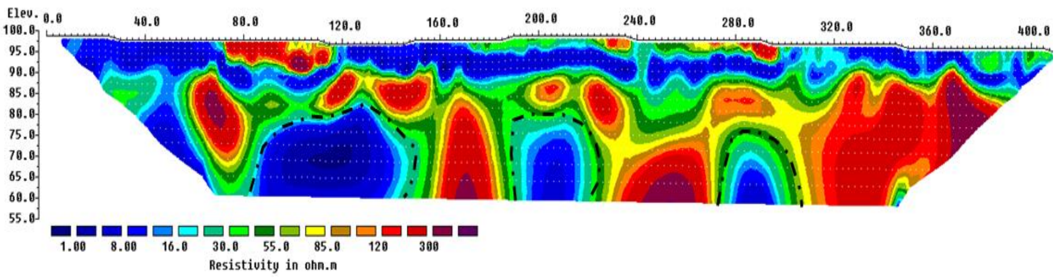


Figure 4.5-9. 2D multi-electrode resistivity cross-section of Line 5-2 and black dot lines present phyllite weak zones.

CHAPTER V
DISCUSSION AND CONCLUSION

5.1 Geology of study area

According to result interpretations of VES, TEM, and 2D-multi electrode data in chapter 4, the study area is covered by lateritic, high leaching old soil. The chemical erosion will leach Silica(SiO_2) from the original soil, and cause accumulation and dissolution of Iron(Fe) and Aluminum Oxide(Al_2O_3) under oxidation and reduction conditions beneath the surface which has groundwater level changes at the same time (Buol et al., 1989). The study area consists of light brown topsoil which is approximately 0.5 – 3 meters thick and is "clay and gravel" or "sand and gravel". The underlying yellowish brown – light grey strong cementation lateritic clay is weathered from "original phyllite or phyletic shale" with various degree of weathering depending on each area. The sediment characteristic in the study area indicates most of sediments are residual deposit as presented in figure 5.1-1.

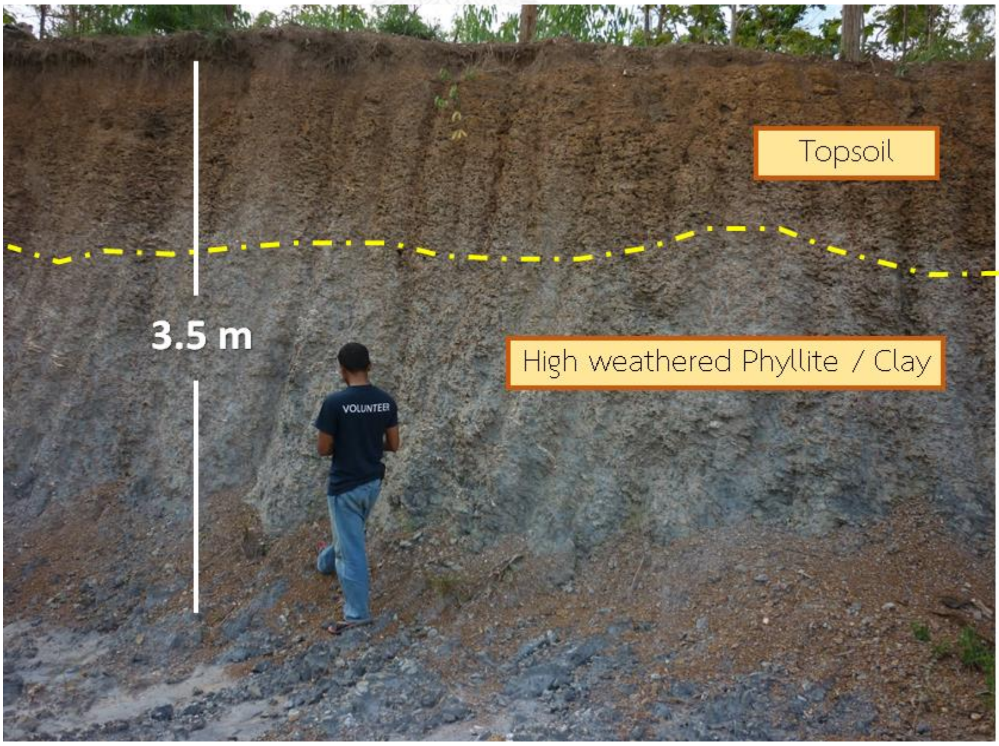


Figure 5.1-1. Soil pit cross section at UTM Grid 549361E, 1813179N

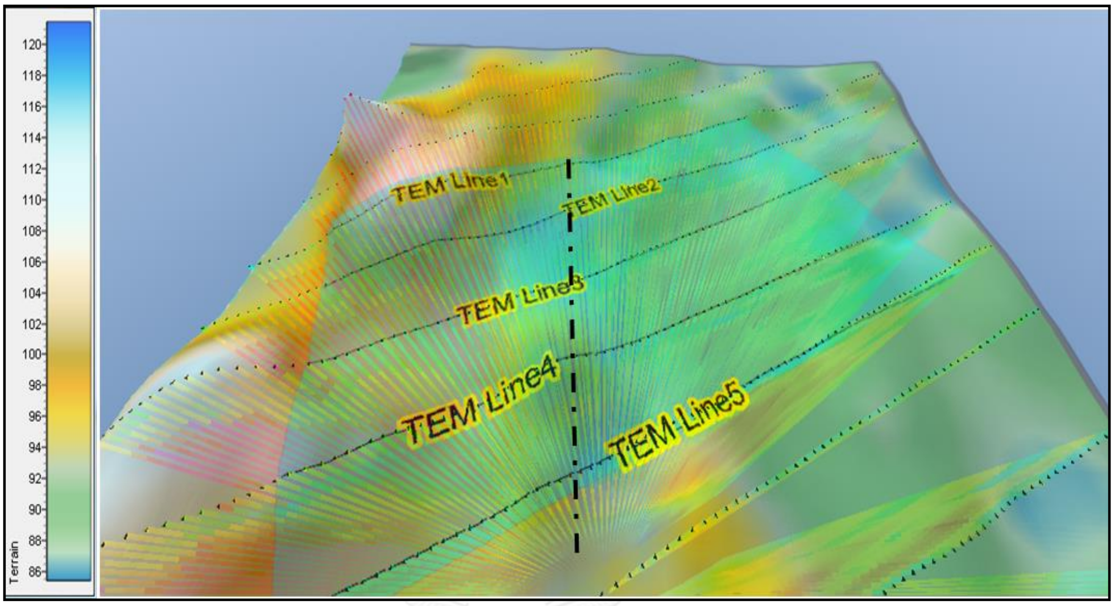


Figure 5.1-2. The study area elevation overlays by TEM survey lines. The black dot line shows weak zone trend which is in blue zone of the study area. (Low resistivity zone is approximately 1 – 25 ohm.meters)

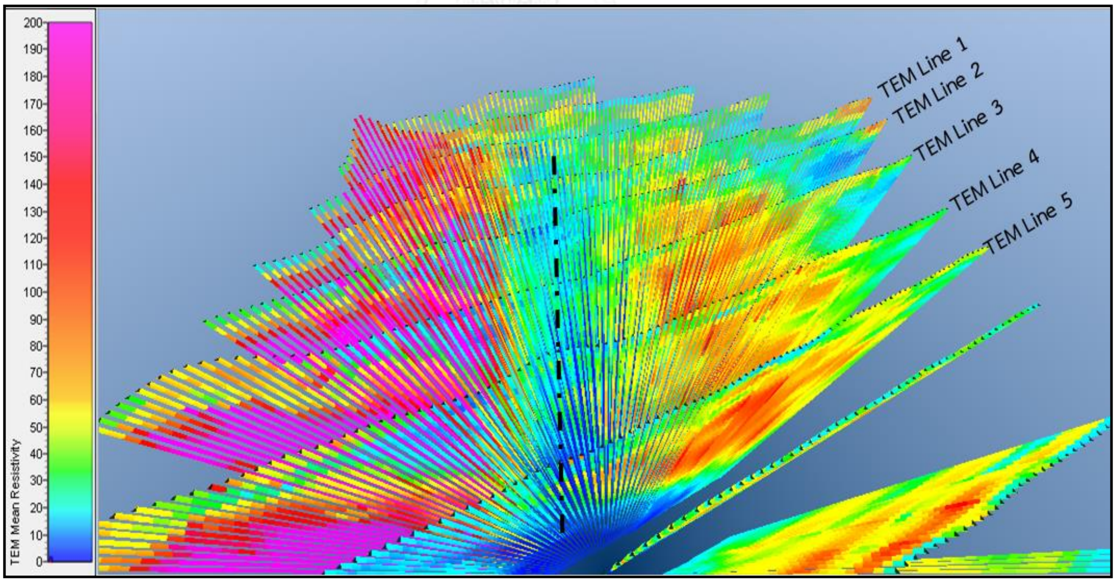


Figure 5.1-3. All geophysical cross-sections of TEM survey line from TEM line1 – TEM line5. The black dot line shows weak zone trend which is in blue zone of the study area. (Low resistivity zone is approximately 1 – 25 ohm.meters)

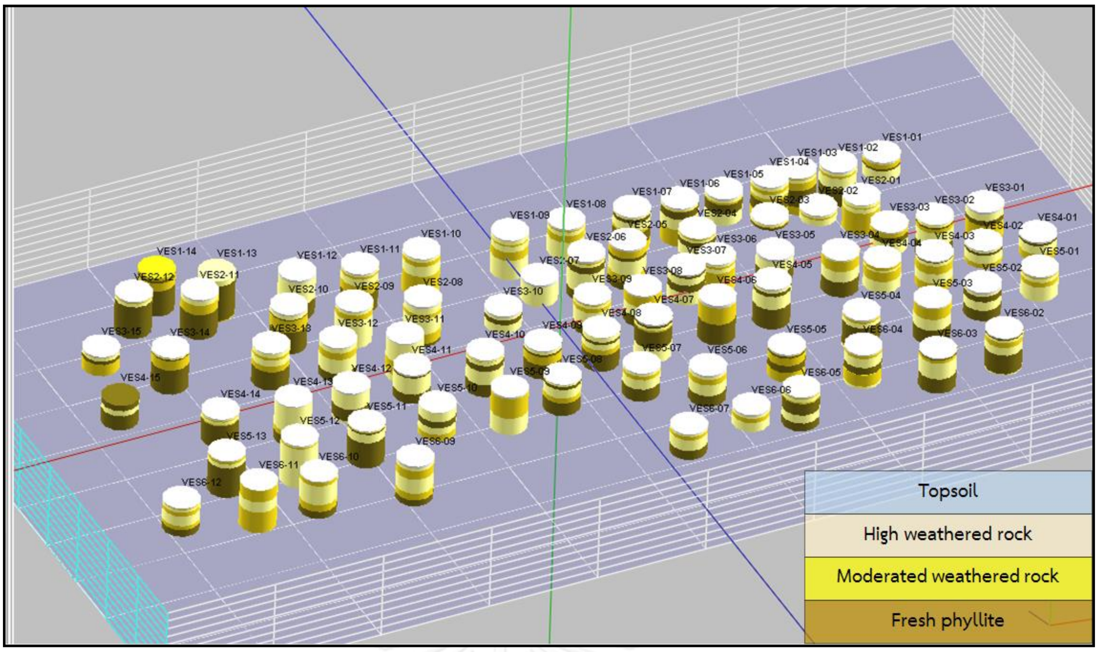


Figure 5.1-4. Interpretation of all VES data points which are presented in 3D sounding point models. Blue is topsoil, Cream is high weathered phyllite, brownish yellow is moderated weathered phyllite, and brown is fresh phyllite.

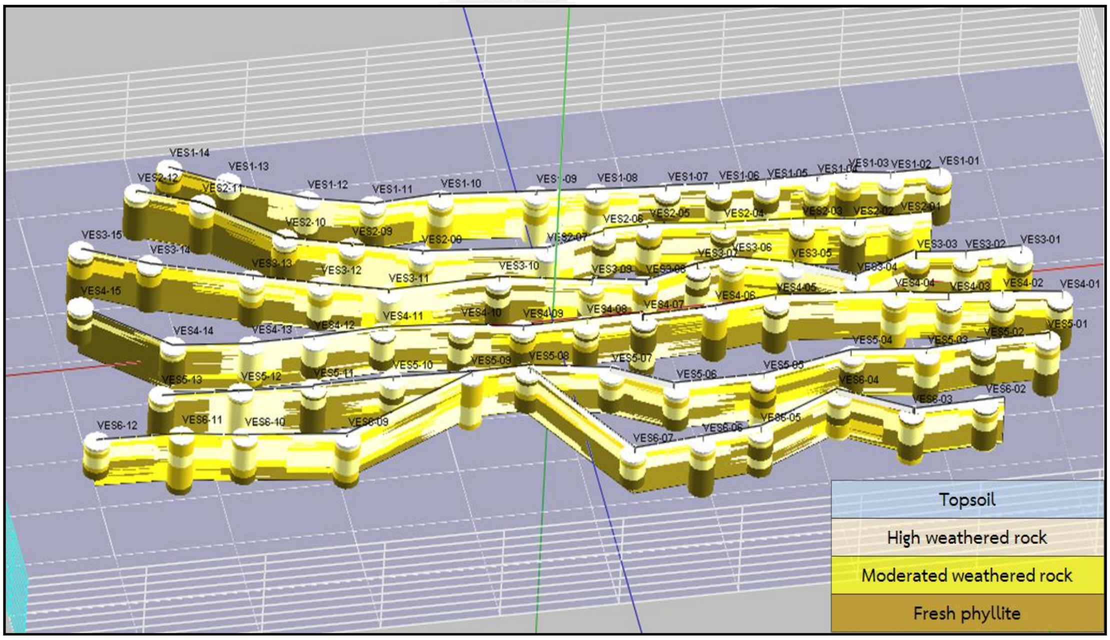


Figure 5.1-5. Lithological cross-sections of VES lines from VES line1 – VES line6, which are plotted with 3D sounding point model. Blue is topsoil, Cream is high weathered phyllite, Brownish yellow is moderated weathered phyllite, and Brown is fresh phyllite.

The bedrock of study area is Silurian – Devonian rocks which are grey – greyish green phyllites that have quartz vein intrusion in some areas. The fresh rocks depth are different in each area depending on degree of weathering and weak zones such as fractures, fault or/and crack zones. Inversion result of TEM data, sounding point's interpretation and cross-section of VES data in the study area are shown in figure 5.1-2, 5.1-3, 5.1-4 and 5.1-5.The VES results are quite conform to TEM results, which are showing shallow fresh bed rocks which mostly occurred in the northwest and southeast of study area, presenting significant major fracture in northeast-southwest pass through VES sounding point comprising VES1-9, VES1-10, VES2-8, VES2-9, VES3-11, VES4-12, VES5-12 and VES6-10, and other is VES1-8, VES2-7, and VES5-9 trend. The significant major fractures zones are composed of thick high weathered phyllite (Cream) interbedded moderated weathered phyllite (brownish yellow), which are not occurred fresh phyllite or in deep zone (up to 70 meters) as shown in "figure 5.1-6, 5.1-7 and 5.1-8" presenting fence diagram crossing the study area. White circle zone is weak zone that consists mostly of high weathered rock.

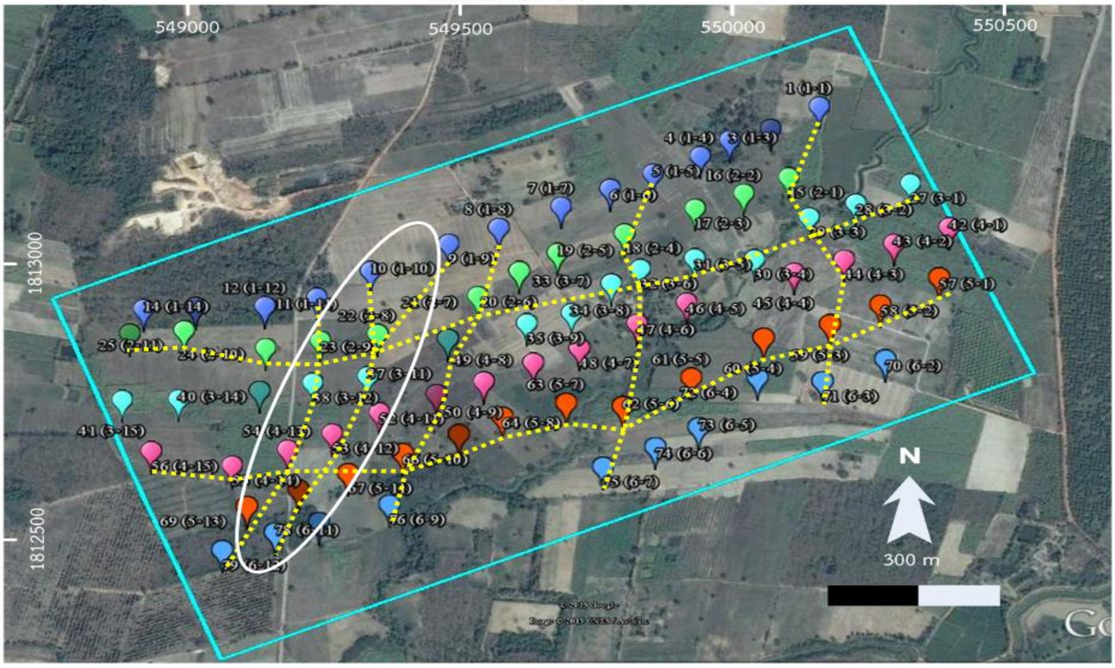


Figure 5.1-6. Top view of fence diagram directions which are presented as yellow lines. Weak zone are presented as white circle.

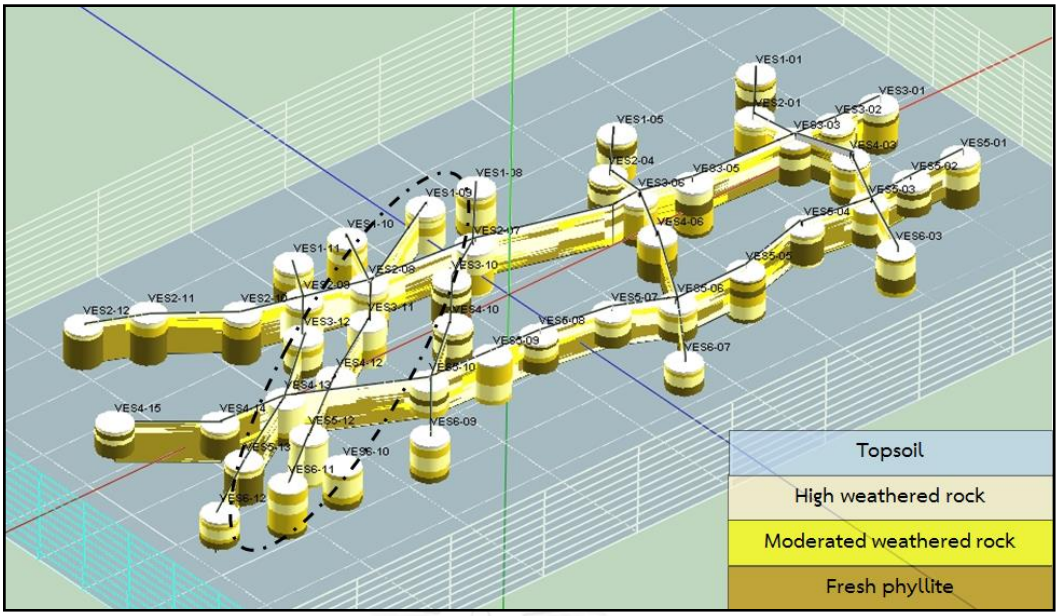


Figure 5.1-7. Fence diagram directions of VES interpretation data. Weak zones or significant fracture zones are presented as black dot circle. Light grey is topsoil, Cream is high weathered phyllite, Brownish yellow is moderated weathered phyllite, and Brown is fresh phyllite.

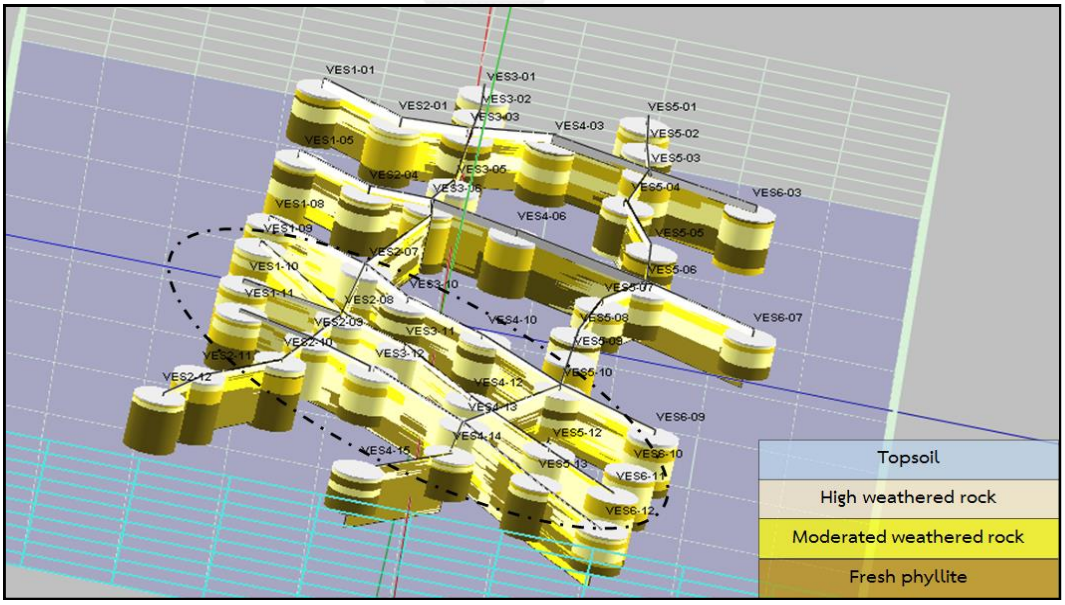


Figure 5.1-8. The different camera view of fence diagram directions of VES interpretation data. Weak zones or significant fracture zones are presented as black dot circle. Light grey is topsoil, Cream is high weathered phyllite, Brownish yellow is moderated weathered phyllite, and Brown is fresh phyllite.

5.2 Hydrogeology and groundwater expected location

Primary aquifer in the study area is Silurian – Devonian metamorphic aquifer (SDmm) from phyllite or phyletic shale. Groundwater is occurred in weathered rock, faults, cracks, or/and fractures zone. This ground water flows along the fractures that are almost aligned in northeast–southwest. The more connected, bigger, and thicker weak zones (weathered rock, fracture, or/and fault zone), the greater chance to find groundwater. Especially, significant weak zones which are presented in fence diagram directions in figure 5.1-7 and 5.1-8, are potential groundwater zones.

According to Figure 5.2-1, E points are weak zones in each 2D multi-electrode survey line providing highly-detailed survey data with its 5-meter electrode spacing. The results clearly show geological structures and present minor weak zone trends in north- south at least 8 lines (presented as yellow line) which are aligned along the main weak zone direction. These minor weak zones are expected to be potential groundwater areas.

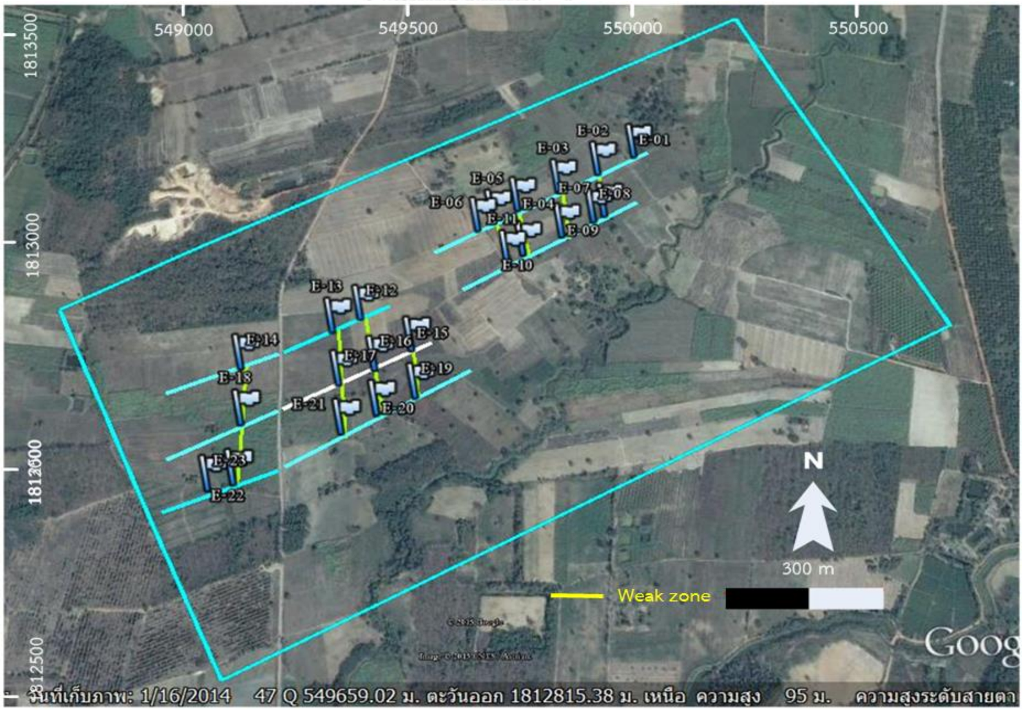


Figure 5.2-1. The potential groundwater expected location points and weak zones that are weathered phyllite or/and fracture zones in the study area.

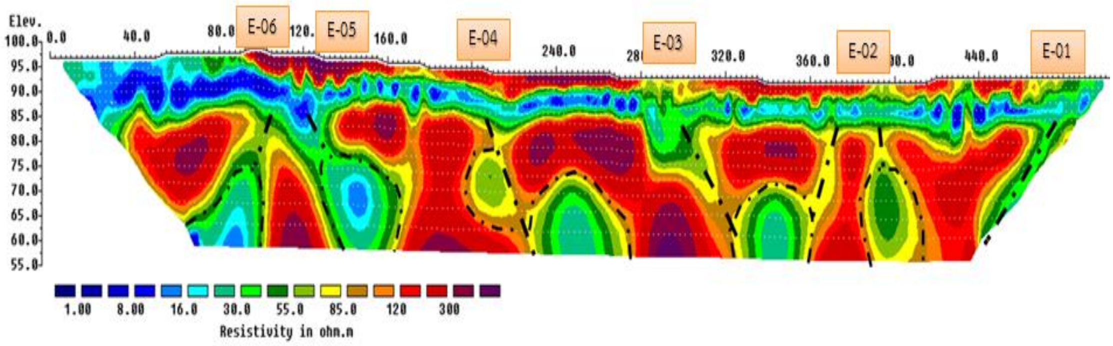


Figure 5.2-2. 2D multi-electrode resistivity cross-section of Line 1 and potential groundwater expected locationE01th – E06th points.

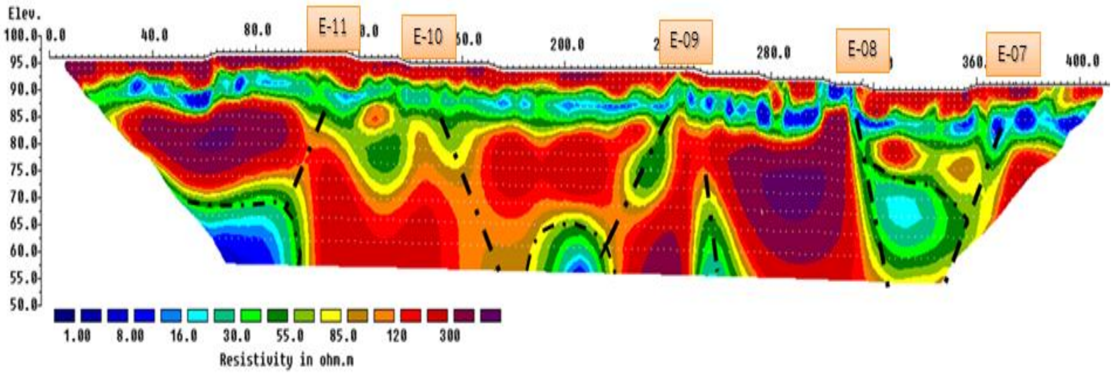


Figure 5.2-3. 2D multi-electrode resistivity cross-section of Line 2 and potential groundwater expected locationE07th – E11th points.

In Line1 and line2 area, most of the rocks are not fresh as line3-1, line 4-1, and line 5-1 area, but they are fresher than line3-2, line4-2, and line5-2 area. However, although there are quite a lot of weak zones (fracture or/and weathered rocks) but all of them are rather small. Most of the weak zones are more than 35 meters depth which have at least 10 groundwater potential expected location points, and 4 weak zone lines consisting of LineE2-E8, E3-E9, E4-E10, and E5-E11 which are presented in Figure5.2-2, and 5.2-3.

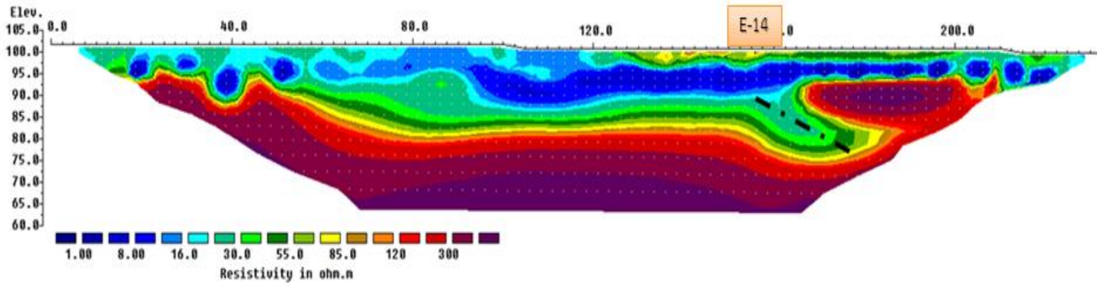


Figure 5.2-4. 2D multi-electrode resistivity cross-section of Line 3-1 and potential groundwater expected locationE14th point.

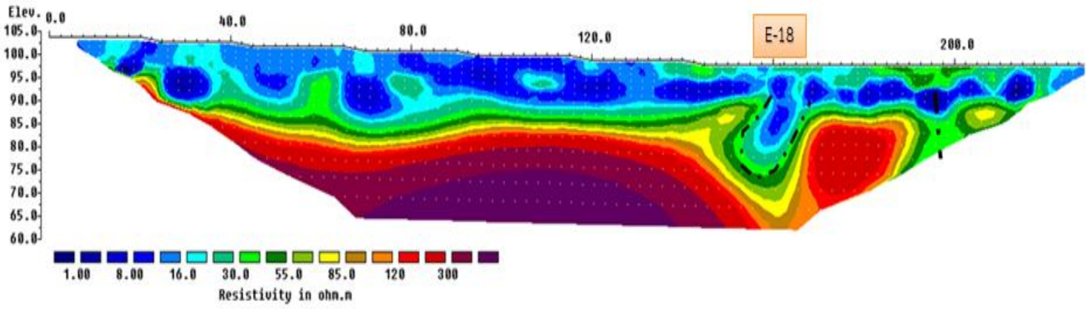


Figure 5.2-5. 2D multi-electrode resistivity cross-section of Line 4-1 and potential groundwater expected locationE18th point.

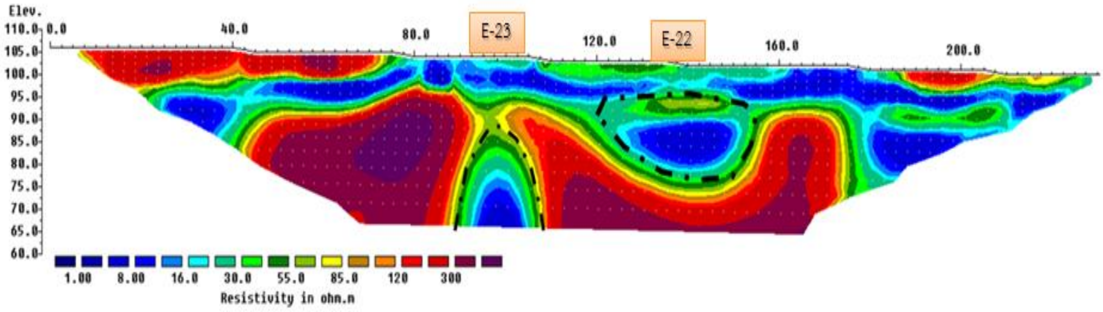


Figure 5.2-6. 2D multi-electrode resistivity cross-section of Line 5-1 and potential groundwater expected locationE22th and E23th points.

Furthermore, the western part of study area (left side of the cement road) comprising LINE4-1 and Line5-1 shows low groundwater potential because rocks are fresh and shallow. However, weak zones aligned along "E14-E17-E22 trend" are discovered and at"E23 point in Line5-1" there appears to be fracture in phyllite, which has groundwater potential zone for ground water well development (Figure5.2-4, Figure5.2-5, and Figure5.2-6).

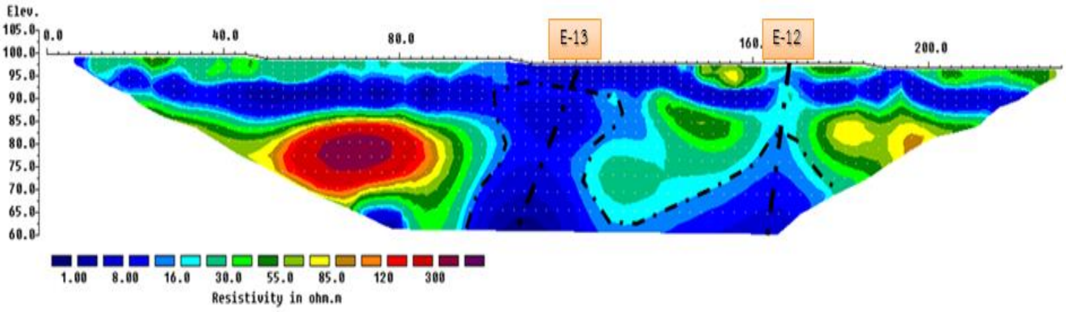


Figure 5.2-7. 2D multi-electrode resistivity cross-section of Line 3-2 and potential groundwater expected locationE12th and E13th points.

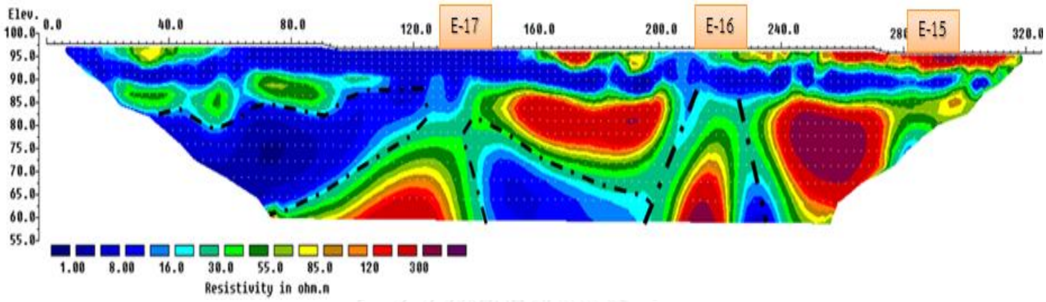


Figure 5.2-8. 2D multi-electrode resistivity cross-section of Line 4-2 and potential groundwater expected locationE15th - E17th points.

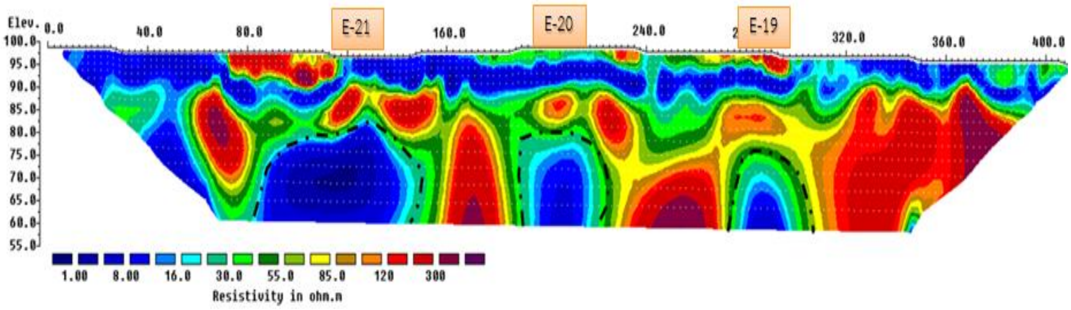


Figure 5.2-9. 2D multi-electrode resistivity cross-section of Line 5-2 and potential groundwater expected locationE19th – E21th points.

In addition, shallow and thick weak zones are discovered along "Line3-2, Line4-2, and Line5-2 areas". These multiply connected weak zones consist of "E15-E19, E12-E16-E20, andE13-E17-E-21" trends. 2D multi-electrode result interpretations conform to VES and TEM survey data, revealing that these area are major significant weak zones ,and they are the most groundwater potential zone in the study area that is suitable for groundwater development (Figure5.2-7, Figure5.2-8, and Figure5.2-9).

5.3 Conceptual model of the study area

Figure 5.3-1 shows surface runoff direction, groundwater flow direction, and expected potential wells. In the surface water system part, the water flows into lower area. Most of it flows from north-western high altitude areas to the south-eastern low altitude areas. Groundwater flow in bedrock is controlled by fractures or/and faults having quite high degree of weathering is potential groundwater zone. Blue cylinders are expected potential wells, most of which are in weak zones. Some of them are in the lower altitude areas.

The western zone sub-surface characteristic of the study area is shallow dense fresh phyllite, making it difficult to explore for groundwater potential. Some areas found are shallow weak zones consisting of fractures or/and weathered rock such as E14-18-22 trend or in E23 points. The eastern zone is rather different from the western zone which is full of phyllites having various degrees of weathering. The probability in finding potential aquifers, therefore, depending on fracture/fault zone connection, weathered zone thickness, and degree of weathering.

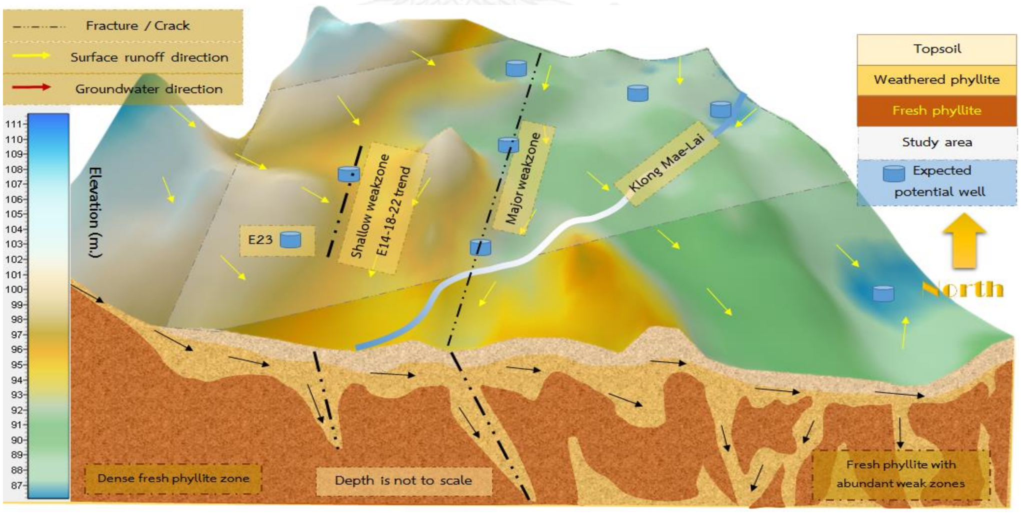


Figure 5.3-1. Conceptual model of study area shows surface runoff, weak zones, groundwater direction and expected potential wells.

5.4 Physical model of water flow system

According to figure 5.4-1, the picture shows water system, geological structures, and hydrogeological units of the study area and the surrounding area. The recharge systems are composed of “R1”, precipitation recharge; “R2” is baseflow recharge from irrigation, perennial and ephemeral streams, and surface runoff water; and “R3” is subsurface recharge. The discharge systems are composed of “D1”, baseflow discharge; “D2” is evapotranspiration discharge; “D3” is well withdrawals discharge; “D4” is subsurface discharge; and “D5” is human activity water consumption.

In the surface water system part, the water flows into mountain stream, and flows to lower discharge area when it rains. Most of water flow from the higher altitude in the western zone to the lower altitude in the eastern zone based on topography elevation. Low land areas recharge water from surface runoff, mountain stream, and Ping River including perennial and ephemeral streams. Surface water will discharge to human activity water consumption, agriculture, and evapotranspiration from trees and etc. Moreover, some surface runoff will flow to lower area according to topography. Sometimes the agricultural area will recharge water which from irrigation when there is an increase in water demand.

In the groundwater system part, the water flows through cracks, fractures or/and faults zone in high mountain, and then flows to lower discharge area. Groundwater flow in hard rock is controlled by fractures or/and fault trends which have quite high degree of weathering and are potential aquifers. According to piezometric level data of ATDEM project (DGR, 2012), the unconsolidated rock aquifers consist of young terrace deposit and old terrace deposit flowing from the western part to the eastern basin. Some groundwater, however, flows to the southeastern area. Furthermore, some of groundwater flow and runoff overland will recharge Ping river and water from Ping river has a chance to flow through aquifer as well. In addition, some groundwater is discharged from system by well withdrawal too.

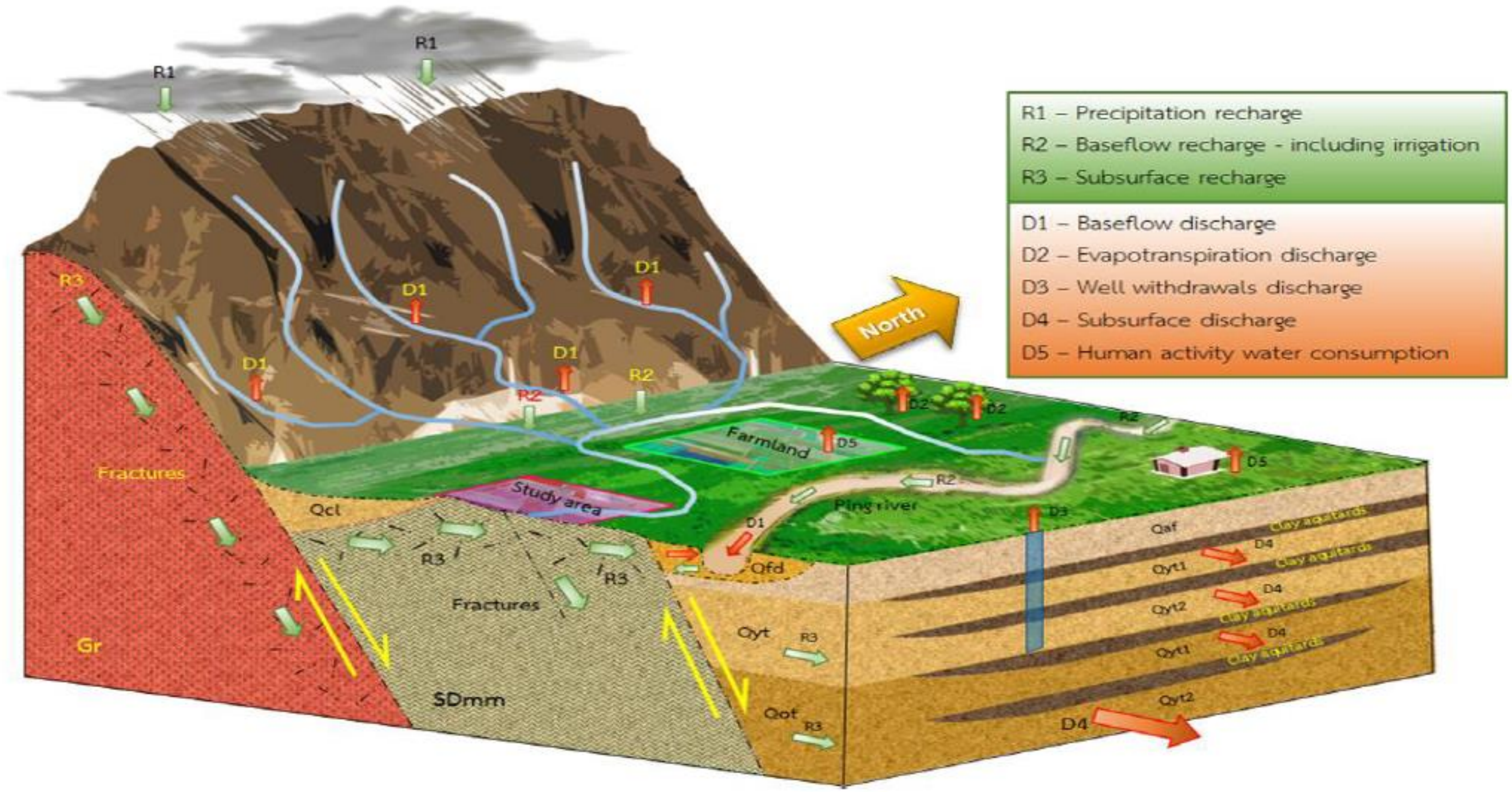


Figure 5.4-1 shows physical model of water systems. Green arrows are recharge directions and red arrows are discharge directions. Unconsolidated aquifer consists of Qyt which is young terrace deposit, Qot is old terrace deposit, Qaf is alluvial fan deposit, Qfd is floodplain deposit, and Qcl is colluvium deposit. Consolidated aquifer consists of Gr is granite and SDmm is Silurian-Devonian meta-sedimentary rock.

5.5 Suggestion and conclusion

The application of geophysical data in combination with field survey and well-logging data can accurately clearly classify and analyze subsurface soil or/and layers characteristic. In this research, it is presented that most sediment characteristic is residual deposit which is different from the first assumption that most of it is old terrace deposit. Because of increasing field survey and geophysical data, classification and analysis of quaternary sediment characteristic are more accurate than previous results. The new interpretation of result can be used to adjust former database of department of groundwater resources for more precise mappings. However, geophysical survey in various techniques have their limitations, for example;

Airborne TEM geophysical survey offers deep penetration depth, high frequency of sounding points with its 20-meter point spacing, fast survey in large area, and can survey inaccessible area such as overgrown weed area or dense forest, which helps provide clear and precise presented geological structures in regional scale. On the other hand, this technique has limitation in its classification capability in high resistivity layers and there is a high risk that the technique will be affected by noise.

VES geophysical ground survey is more accurate and can classify high resistivity layer better than airborne TEM geophysical survey. In addition, their results comparing with wireline logging data are quite accurate. On the other hand, this technique takes rather long survey time if the research needs highly-detailed and high quantity of data. Furthermore, the penetration depth is shallower than airborne TEM geophysical survey and cannot be used to survey inaccessible area such as overgrown weed area, dense forest, or dense sugar cane field, however, it is more flexible than 2D multi electrode survey. This research uses Schlumberger configuration which offers quite deep penetration depth and quite accurate horizontal and vertical geological structure survey. In addition, the electrode spacing can be easily extended.

2D multi-electrode geophysical ground survey captures the highest data detail with 5-meters electrode spacing and results from this technique are more accurate than VES geophysical ground survey and airborne TEM geophysical survey. In addition, it can precisely and clearly survey subsurface structures such as significant cracks, fractures, or/and faults. On the other hand, this technique has shallow penetration depth (Maximum penetration depth is 40 – 50 meters depending on cable length and configuration), and calls for large budget because the instrument rental price is rather high and at least 3 workers including instrument operator for work must be hired. In addition, this technique faces more difficulty in accessing some areas than VES ground survey. The area suitable for this technique should be clear or has a pathway where cables can be dragged through. Furthermore, the other 2D multi-electrode limitation is that cables cannot be dragged across roads wider than 5 meters or more, making several areas in accessible for survey. In addition, this research relies on dipole-dipole configuration that accurately explores horizontal changes in subsurface structures (vertical structures) such as significant vertical fractures, or/and dip slip faults.

Combining the advantage of each technique will reduce limitation in terms of area data access and better data accuracy. Moreover, it will reduce budget, cost, and survey time especially for consolidated rock aquifers survey as most groundwater is stored in cracks, fractures, or/and faults, which makes it difficult to explore and calls for highly-detailed and accurate data to discover the exact location of groundwater potential areas. Particularly, there is very limited secondary data in the study area and potential aquifers are in hard rocks (Silurian – Devonian metamorphic rock aquifer). Application of TEM and direct current resistivity in combination with field survey and well-logging data produce accurate and clear results of the study that will be helpful and acts as a guideline for drilling groundwater in this area or even consolidated rock aquifers in other areas in the future.

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APPENDIX

1. VES Line 1 interpretation results

Table A.1-1. 1st lateritic topsoil layer consisting of sandy clay and gravel and is 3.17 meters thick, 2nd high weathered phyllite layer is 0.55 meters thick, 3rd moderated weathered phyllite layer is 7.80 meters thick, 4th fresh phyllite layer is 3.55 meters thick., 5th high weathered phyllite layer is 18.80 meters thick, 6th fresh phyllite layer is 32.38 meters thick, and 7th moderated weathered phyllite layer.

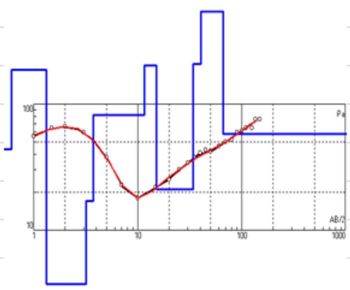
Apparent resistivity curve VES1-1	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	44.00	0.61	0.61	Topsoil
	2	188.00	0.71	1.32	
	3	3.73	1.85	3.17	
	4	17.00	0.55	3.72	High wethered phyllite
	5	82.40	7.80	11.52	Moderated weathered phyllite
	6	202.00	3.55	15.07	Fresh phyllite
	7	21.00	18.80	33.87	High wethered phyllite
	8	209.00	6.48	40.35	Fresh phyllite
	9	1458.00	25.90	66.25	
	10	57.90			Moderated weathered phyllite

Table A.1-2. 1st topsoil layer consisting of sandy clay and clay which is 3.19 meters thick, 2nd high weathered phyllite layer is 4.16 meters thick, 3rd moderated weathered phyllite layer is 4.40 meters thick, 4th high weathered phyllite layer is 17.90 meters thick, 5th fresh phyllite layer is 31.02 meters thick, and 6th high weathered phyllite layer.

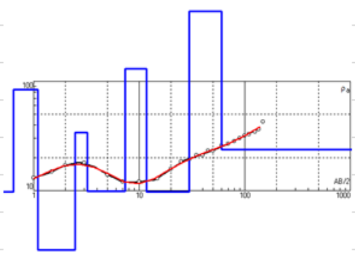
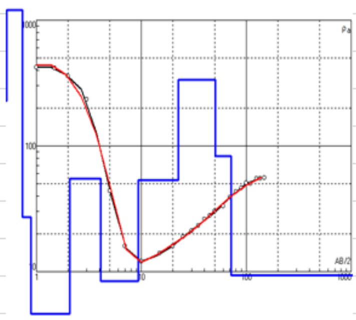
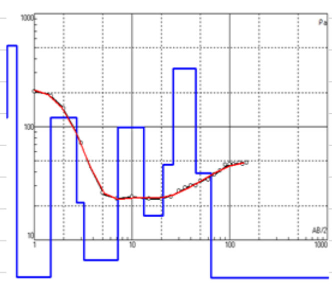
Apparent resistivity curve VES1-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	9.67	0.64	0.64	Topsoil
	2	84.09	0.46	1.10	
	3	2.86	1.35	2.45	
	4	34.24	0.74	3.19	
	5	9.83	4.16	7.35	High wethered phyllite
	6	131.20	4.40	11.75	Moderated weathered phyllite
	7	9.70	17.90	29.65	High wethered phyllite
	8	438.80	31.02	60.67	Fresh phyllite
	9	23.62			High wethered phyllite

Table A.1-3. 1st lateritic topsoil layer consisting of sand and gravel and underlying clay which is 2.08 meters thick, 2nd moderated weathered phyllite layer is 2.03 meters thick, 3rd high weathered phyllite layer is 5.20 meters thick, 4th moderated weathered phyllite layer is 13.20 meters thick, 5th fresh phyllite layer is 27.90 meters thick, 6th moderated weathered phyllite layer is 21.20 meters thick, and 7th high weathered phyllite layer.



Apparent resistivity curve VES1-3	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	229.00	0.26	0.26	Topsoil
	2	1210.00	0.47	0.73	
	3	27.10	0.15	0.88	
	4	2.16	1.20	2.08	
	5	54.70	2.03	4.11	Moderated weathered phyllite
	6	8.37	5.20	9.31	High wethered phyllite
	7	53.50	13.20	22.51	Moderated weathered phyllite
	8	334.00	27.90	50.41	Fresh phyllite
	9	83.40	21.20	71.61	Moderated weathered phyllite
	10	9.30			High wethered phyllite

Table A.1-4. 1st lateritic topsoil layer consisting of sand and gravel and underlying clay which is 2.69 meters thick, 2nd high weathered phyllite layer is 4.51 meters thick, 3rd moderated weathered phyllite layer is 6.09 meters thick, 4th high weathered phyllite layer is 7.38 meters thick, 5th moderated phyllite layer is 5.83 meters thick, 6th fresh phyllite layer is 18.60 meters thick, and 7th moderated weathered phyllite layer is 19.10 meters thick, 8th high weathered phyllite layer.



Apparent resistivity curve VES1-4	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	120.00	0.24	0.24	Topsoil
	2	518.00	0.42	0.66	
	3	4.71	0.81	1.47	
	4	120.00	1.22	2.69	
	5	21.30	0.54	3.23	High wethered phyllite
	6	6.59	3.97	7.20	
	7	98.80	6.09	13.29	Moderated weathered phyllite
	8	16.40	7.38	20.67	High wethered phyllite
	9	46.50	5.83	26.50	Moderated weathered phyllite
	10	328.00	18.60	45.10	Fresh phyllite
	11	38.80	19.10	64.20	Moderated weathered phyllite
	12	3.60			High wethered phyllite

Table A.1-5. 1st lateritic topsoil layer consisting of sand and gravel and underlying sandy clay which is 2.93 meters thick, 2nd high weathered phyllite layer is 4.30 meters thick, 3rd moderated weathered phyllite layer is 3.15 meters thick, 4th fresh phyllite layer is 16.80 meters thick, 5th high weathered phyllite layer is 19.30 meters thick, 6th moderated weathered phyllite layer is 28.60 meters thick, and 7th fresh phyllite layer.

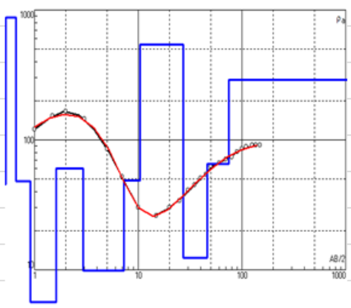
Apparent resistivity curve VES1-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	45.60	0.27	0.27	Topsoil
	2	877.00	0.40	0.67	
	3	48.20	0.25	0.92	
	4	5.67	0.70	1.62	
	5	60.00	1.31	2.93	
	6	9.87	4.30	7.23	High wethered phyllite
	7	48.80	3.15	10.38	Moderated weathered phyllite
	8	544.00	16.80	27.18	Fresh phyllite
	9	12.40	19.30	46.48	High wethered phyllite
	10	65.60	28.60	75.08	Moderated weathered phyllite
	11	269.00			Fresh phyllite

Table A.1-6. 1st lateritic topsoil layer consisting of sand and gravel which is 2.21 meters thick, 2nd high weathered phyllite layer is 2.93 meters thick, 3rd moderated weathered phyllite layer is 1.62 meters thick, 4th fresh phyllite layer is 12.23 meters thick, 5th high weathered phyllite layer is 18.93 meters thick, 6th moderated weathered phyllite layer is 28.52 meters thick, and 7th fresh phyllite layer.

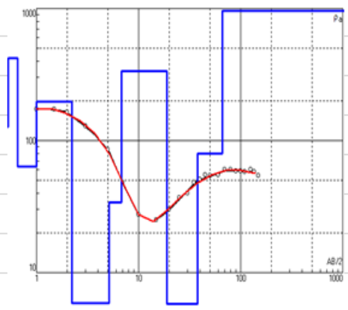
Apparent resistivity curve VES1-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	127.20	0.36	0.36	Topsoil
	2	423.60	0.29	0.65	
	3	63.80	0.35	1.00	
	4	198.10	1.21	2.21	
	5	5.85	2.93	5.14	High wethered phyllite
	6	34.00	1.62	6.76	Moderated weathered phyllite
	7	337.00	12.23	18.99	Fresh phyllite
	8	5.80	18.93	37.92	High wethered phyllite
	9	80.15	28.52	66.44	Moderated weathered phyllite
	10	956.10			Fresh phyllite

Table A.1-7. 1st lateritic topsoil layer consisting of sandy clay and underlying laterite which is 1.74 meters thick, 2nd high weathered phyllite layer is 2.93 meters thick,3rd moderated weathered phyllite layer is 5.83 meters thick, 4th high weathered phyllite layer is 13.80 meters thick, 5th moderated weathered phyllite layer is 4.92 meters thick, 6th fresh phyllite layer is 20.30 meters thick, 7th moderated weathered phyllite layer is 15.90 meters thick, and 8th high weathered phyllite layer.

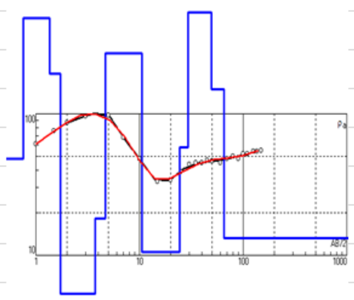
Apparent resistivity curve VES1-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	48.00	0.76	0.76	Topsoil
	2	473.00	0.60	1.36	
	3	193.00	0.38	1.74	
	4	5.32	1.98	3.72	High wethered phyllite
	5	18.20	0.95	4.67	
	6	269.00	5.83	10.50	Fresh phyllite
	7	10.60	13.80	24.30	High wethered phyllite
	8	57.80	4.92	29.22	Moderated weathered phyllite
	9	524.00	20.30	49.52	Fresh phyllite
	10	150.00	15.90	65.42	Moderated weathered phyllite
	11	13.20			High wethered phyllite

Table A.1-8. 1st lateritic topsoil layer mostly consisting of clay and some gravel which is 3.14 meters thick, 2nd moderated weathered phyllite layer is 2.15 meters thick, 3rd high weathered phyllite layer is 6.65 meters thick, 4th moderated weathered phyllite layer is 11.41 meters thick, 5th high weathered phyllite layer is 29.92 meters thick, 6th moderated weathered phyllite layer is 20.59 meters thick, and 7th fresh phyllite layer.

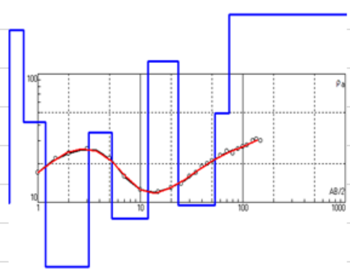
Apparent resistivity curve VES1-8	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	9.90	0.49	0.49	Topsoil
	2	220.50	0.24	0.73	
	3	41.97	0.45	1.18	
	4	3.15	1.96	3.14	
	5	34.90	2.15	5.29	Moderated weathered phyllite
	6	7.50	6.65	11.94	High wethered phyllite
	7	125.50	11.41	23.35	Moderated weathered phyllite
	8	9.50	29.92	53.27	High wethered phyllite
	9	49.72	20.59	73.86	Moderated weathered phyllite
	10	290.80			Fresh phyllite

Table A.1-9. 1st lateritic topsoil layer consisting of clay and gravel which is 1.98 meters thick, 2nd high weathered phyllite layer is 6.50 meters thick, 3rd moderated weathered phyllite layer is 2.72 meters thick, 4th high weathered phyllite layer is 9.81 meters thick, 5th moderated weathered phyllite layer is 15.30 meters thick, 6th high weathered phyllite layer is 44.50 meters thick, and 7th fresh phyllite layer.

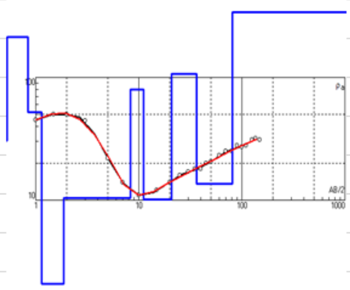
Apparent resistivity curve VES1-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	30.40	0.49	0.49	Topsoil
	2	214.00	0.35	0.84	
	3	52.00	0.30	1.14	
	4	2.08	0.72	1.86	
	5	10.40	6.50	8.36	High wethered phyllite
	6	79.30	2.72	11.08	Moderated weathered phyllite
	7	10.20	9.81	20.89	High wethered phyllite
	8	107.00	15.30	36.19	Moderated weathered phyllite
	9	13.60	44.50	80.69	High wethered phyllite
	10	340.00			Fresh phyllite

Table A.1-10. 1st lateritic topsoil layer consisting of clay and gravel which is 1.90 meters thick, 2nd high weathered phyllite layer is 4.03 meters thick,3rd moderated weathered phyllite layer is 7.46 meters thick, 4th high weathered phyllite layer is 17.70 meters thick, 5th moderated weathered phyllite layer is 38.60 meters thick, and 6th high weathered phyllite layer.

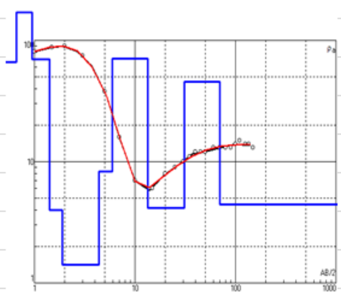
Apparent resistivity curve VES1-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	66.10	0.66	0.66	Topsoil
	2	453.00	0.29	0.95	
	3	69.60	0.46	1.41	
	4	3.97	0.49	1.90	
	5	1.42	2.50	4.40	High wethered phyllite
	6	8.25	1.53	5.93	
	7	70.30	7.46	13.39	Moderated weathered phyllite
	8	4.16	17.70	31.09	High wethered phyllite
	9	45.50	38.60	69.69	Moderated weathered phyllite
	10	4.43			High wethered phyllite

Table A.1-11. 1st lateritic topsoil layer consisting of laterite and underlying clay which is 2.80 meters thick, 2nd high weathered phyllite layer is 1.91 meters thick,3rd moderated weathered phyllite layer is 4.35 meters thick, 4th high weathered phyllite layer is 12.30 meters thick, 5th moderated weathered phyllite layer is 16.00 meters thick, and 6th fresh phyllite layer.

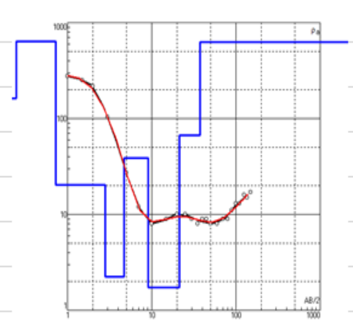
Apparent resistivity curve VES1-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	162.00	0.25	0.25	Topsoil
	2	639.00	0.47	0.72	
	3	20.20	2.08	2.80	
	4	2.24	1.91	4.71	High wethered phyllite
	5	38.70	4.35	9.06	Moderated weathered phyllite
	6	1.74	12.30	21.36	High wethered phyllite
	7	66.80	16.00	37.36	Moderated weathered phyllite
	8	629.00			Fresh phyllite

Table A.1-12. 1st lateritic topsoil layer consisting of laterite, and underlying unsaturated weathered phyllite which is 3.90 meters thick, 2nd high weathered phyllite layer is 38.34 meters thick, and 3rd fresh phyllite layer.

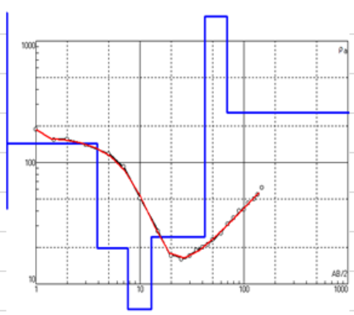
Apparent resistivity curve VES1-12	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	3421.00	0.19	0.19	Topsoil
	2	41.40	0.11	0.30	
	3	322.00	0.18	0.49	
	4	144.00	3.41	3.90	
	5	19.70	3.76	7.66	High wethered phyllite
	6	6.18	5.18	12.84	
	7	24.50	29.40	42.24	
	8	1585.00	26.20	68.44	Fresh phyllite
	9	259.00			

Table A.1-13. 1st lateritic topsoil layer consisting of sand and gravel which is 1.14 meters thick, 2nd moderated weathered phyllite layer is 3.97 meters thick, and 3rd high weathered phyllite layer is 9.11 meters thick,4th fresh phyllite layer is 60.72 meters thick, and 5th high weathered phyllite layer.

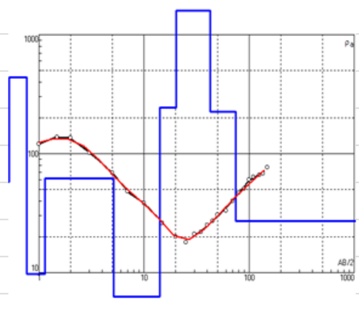
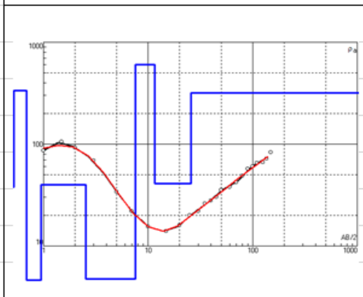
Apparent resistivity curve VES1-13	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	58.00	0.29	0.29	Topsoil
	2	439.00	0.48	0.77	
	3	9.79	0.37	1.14	
	4	62.00	3.97	5.11	Moderated weathered phyllite
	5	6.25	9.11	14.22	High wethered phyllite
	6	243.00	5.92	20.14	Fresh phyllite
	7	1602.00	22.70	42.84	
	8	225.00	32.10	74.94	
	9	27.00			High wethered phyllite

Table A.1-14. 1st lateritic topsoil layer consisting of sandy clay and rock fragments which is 2.56 meters thick, 2nd high weathered phyllite layer is 5.02 meters thick, and 3rd fresh phyllite layer is 4.03 meters thick,4th moderated weathered phyllite layer is 14.00 meters thick, and 5thfresh phyllite layer.

Apparent resistivity curve VES1-14	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	37.80	0.25	0.25	Topsoil
	2	336.00	0.45	0.70	
	3	2.98	0.26	0.96	
	4	39.90	1.60	2.56	
	5	4.77	5.02	7.58	High wethered phyllite
	6	600.00	4.03	11.61	Fresh phyllite
	7	41.10	14.00	25.61	Moderated weathered phyllite
	8	319.00			Fresh phyllite

2. VES Line 2 interpretation results

Table A.2-1. 1st topsoil layer consisting of sandy clay and underlying clay or high weathered phyllite which is 5.62 meters thick, 2nd moderated weathered phyllite layer is 1.98 meters thick, 3rd high weathered phyllite layer is 7.32 meters thick., 4th high weathered phyllite layer is 37.84 meters thick, and 5th fresh phyllite layer.

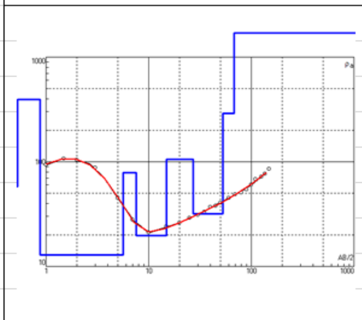
Apparent resistivity curve VES2-1	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	57.95	0.42	0.42	Topsoil
	2	394.40	0.46	0.88	
	3	12.93	4.74	5.62	
	4	79.15	1.98	7.60	Moderated weathered phyllite
	5	19.61	7.32	14.92	High wethered phyllite
	6	105.40	12.05	26.97	Moderated weathered phyllite
	7	31.63	25.79	52.76	
	8	291.50	14.78	67.54	Fresh phyllite
	9	2160.00			

Table A.2-2. 1st lateritic topsoil layer consisting of sandy clay and underlying laterite which is 1.88 meters thick, 2nd high weathered phyllite layer is 2.57 meters thick, 3rdmoderated weathered phyllite layer is 3.34 meters thick, 4th high weathered phyllite layer is 10.60 meters thick, and 5th fresh phyllite layer.

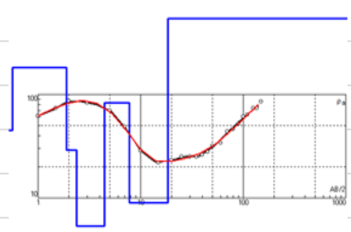
Apparent resistivity curve VES2-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	44.70	0.56	0.56	Topsoil
	2	183.00	1.32	1.88	
	3	28.90	0.48	2.36	High wethered phyllite
	4	5.37	2.09	4.45	
	5	83.00	3.34	7.79	Moderated weathered phyllite
	6	8.99	10.60	18.39	High wethered phyllite
	7	1201.00			Fresh phyllite

Table A.2-3. 1st lateritic topsoil layer consisting of clayey sand and gravel which is 1.44 meters thick, 2nd high weathered phyllite layer is 3.22 meters thick, 3rd moderated weathered phyllite layer is 1.96 meters thick, 4th fresh phyllite layer is 38.71 meters thick, 5th moderated weathered phyllite layer is 21.70 meters thick, and 6th fresh phyllite layer.

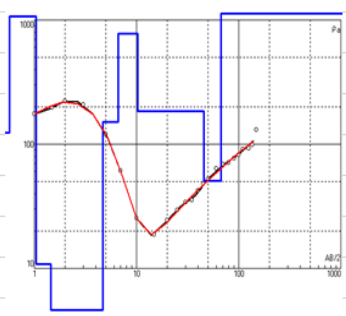
Apparent resistivity curve VES2-3	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	123.00	0.57	0.57	Topsoil
	2	1069.00	0.47	1.04	
	3	10.80	0.41	1.44	
	4	4.35	3.22	4.66	High wethered phyllite
	5	152.00	1.96	6.62	Moderated weathered phyllite
	6	778.00	3.71	10.33	Fresh phyllite
	7	184.00	35.00	45.33	
	8	50.40	21.70	67.03	Moderated weathered phyllite
	9	1123.00			Fresh phyllite

Table A.2-4. 1st lateritic topsoil layer consisting of clayey sand and gravel which is 1.44 meters thick, 2nd moderated weathered phyllite layer is 2.52 meters thick, 3rd high weathered phyllite layer is 4.35 meters thick, 4th fresh phyllite layer is 8.61 meters thick, 5th high weathered phyllite layer is 20.90 meters thick, and 6th fresh phyllite layer.

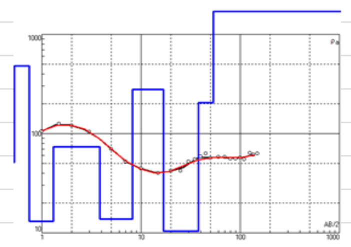
Apparent resistivity curve VES2-4	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	51.10	0.32	0.32	Topsoil
	2	481.00	0.43	0.74	
	3	13.00	0.56	1.30	
	4	73.80	2.52	3.82	Moderated weathered phyllite
	5	13.80	4.35	8.17	High wethered phyllite
	6	279.00	8.61	16.78	Fresh phyllite
	7	10.40	20.90	37.68	High wethered phyllite
	8	206.00	15.90	53.58	Fresh phyllite
	9	2025.00			

Table A.2-5. 1st lateritic topsoil layer consisting of gravelly clay and underlying clay or high weathered phyllite which is 3.29 meters thick, 2nd moderated weathered phyllite layer is 12.10 meters thick, 3rd fresh phyllite layer is 5.33 meters thick, 4th high weathered phyllite layer is 23.80 meters thick, 5th moderated weathered phyllite layer is 12.40 meters thick, and 6th fresh phyllite layer.

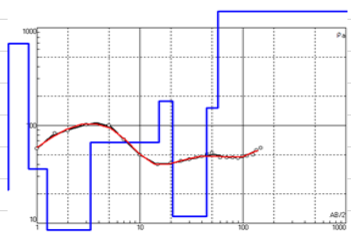
Apparent resistivity curve VES2-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	21.80	0.31	0.31	Topsoil
	2	693.00	0.51	0.83	
	3	36.10	0.44	1.26	
	4	8.55	2.03	3.29	
	5	67.10	12.10	15.39	Moderated weathered phyllite
	6	178.00	5.33	20.72	Fresh phyllite
	7	11.80	23.80	44.52	High wethered phyllite
	8	152.00	12.40	56.92	Moderated weathered phyllite
	9	1477.00			Fresh phyllite

Table A.2-6. 1st lateritic topsoil layer consisting of gravelly clay and underlying clay or high weathered phyllite which is 3.25 meters thick, 2nd moderated weathered phyllite layer is 2.70 meters thick, 3rd high weathered phyllite layer is 4.50 meters thick, 4th fresh phyllite layer is 11.30 meters thick, 5th high weathered phyllite layer is 32.10 meters thick, and 6th fresh phyllite.

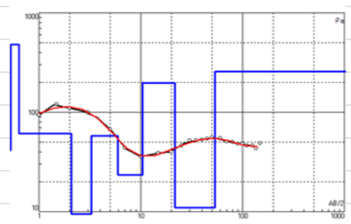
Apparent resistivity curve VES2-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	41.40	0.29	0.29	Topsoil
	2	478.00	0.35	0.63	
	3	61.10	1.45	2.08	
	4	9.47	1.17	3.25	
	5	57.60	2.70	5.95	Moderated weathered phyllite
	6	23.50	4.50	10.45	High wethered phyllite
	7	196.00	11.30	21.75	Fresh phyllite
	8	11.00	32.10	53.85	High wethered phyllite
	9	258.00			Fresh phyllite

Table A.2-7. 1st topsoil layer mostly consisting of clay which is 1.31 meters thick, 2nd high weathered phyllite layer is 37.14 meters thick, 3rd moderated weathered phyllite layer is 37.90 meters thick, and 4th high weathered phyllite layer.

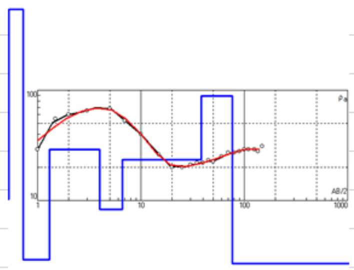
Apparent resistivity curve VES2-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	10.30	0.26	0.26	
	2	616.00	0.46	0.72	Topsoil
	3	2.89	0.59	1.31	
	4	29.00	2.70	4.01	
	5	8.31	2.64	6.65	High wethered phyllite
	6	23.50	31.80	38.45	
	7	88.50	37.90	76.35	Moderated weathered phyllite
	8	2.69			High wethered phyllite

Table A.2-8. 1st topsoil layer consisting of clay and gravel and underlying clay or high weathered phyllite which is 3.15 meters thick, 2nd high weathered phyllite layer is 10.70 meters thick, 3rd moderated weathered phyllite layer is 7.48 meters thick, 4th high weathered phyllite layer is 27.10 meters thick, 5th moderated weathered phyllite layer is 16.80 meters thick, and 6th fresh phyllite layer.

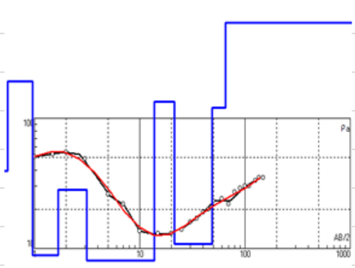
Apparent resistivity curve VES2-8	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	39.30	0.55	0.55	
	2	192.00	0.41	0.96	Topsoil
	3	8.87	0.71	1.67	
	4	28.40	1.48	3.15	
	5	8.07	10.70	13.85	High wethered phyllite
	6	134.00	7.48	21.33	Moderated weathered phyllite
	7	10.90	27.10	48.43	High wethered phyllite
	8	120.00	16.80	65.23	Moderated weathered phyllite
	9	884.00			Fresh phyllite

Table A.2-9. 1st topsoil layer consisting of sandy clay and gravel which is 2.50 meters thick, 2nd high weathered phyllite layer is 4.2 meters thick, 3rd moderated weathered phyllite layer is 9.36 meters thick, 4th high weathered phyllite layer

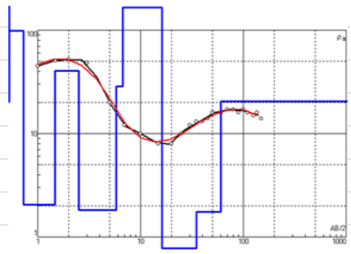
Apparent resistivity curve VES2-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	20.20	0.29	0.29	Topsoil
	2	344.00	0.22	0.51	
	3	98.50	0.22	0.73	
	4	2.04	0.74	1.47	
	5	40.20	1.03	2.50	
	6	1.82	3.31	5.81	High wethered phyllite
	7	28.70	0.89	6.70	
	8	165.00	9.36	16.06	Moderated weathered phyllite
	9	0.78	18.90	34.96	High wethered phyllite
	10	1.77	25.10	60.06	
	11	20.60			

Table A.2-10. 1st lateritic topsoil layer consisting of sandy clay and gravel which is 3.04 meters thick, 2ndhigh weathered phyllite layer is 5.88 meters thick, 3rdfresh phyllite layer is 2.16 meters thick, 4thmoderated weathered phyllite layer 20.64 meters thick, and 5th fresh phyllite layer.

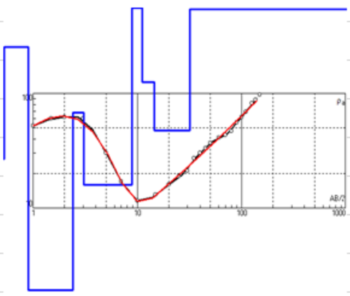
Apparent resistivity curve VES2-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	26.60	0.37	0.37	Topsoil
	2	255.00	0.53	0.90	
	3	1.93	1.51	2.41	
	4	68.20	0.64	3.04	
	5	15.90	5.88	8.92	High wethered phyllite
	6	559.00	2.16	11.08	Fresh phyllite
	7	125.00	3.44	14.52	Moderated weathered phyllite
	8	47.40	17.20	31.72	
	9	3336.00			Fresh phyllite

Table A.2-11. 1st lateritic topsoil layer consisting of clay and gravel which is 2.46 meters thick, 2nd high weathered phyllite layer is 7.55 meters thick, 3rd moderated weathered phyllite layer 16.60 meters thick, and 4th fresh phyllite layer.

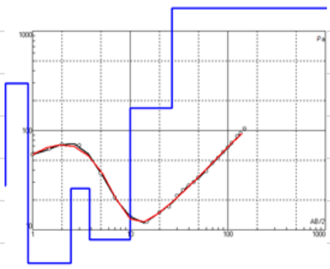
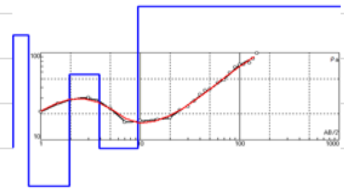
Apparent resistivity curve VES2-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	28.00	0.36	0.36	Topsoil
	2	299.00	0.54	0.90	
	3	2.99	1.56	2.46	
	4	26.10	1.38	3.84	High wethered phyllite
	5	8.00	6.17	10.01	
	6	167.00	16.60	26.61	Moderated weathered phyllite
	7	4725.00			Fresh phyllite

Table A.2-12 1st lateritic topsoil layer consisting of clay and gravel which is 1.95 meters thick, 2nd moderated weathered phyllite layer is 1.93 meters thick, 3rd high weathered phyllite layer 5.64 meters thick, and 4th fresh phyllite layer.

Apparent resistivity curve VES2-12	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	8.24	0.30	0.30	Topsoil
	2	159.00	0.46	0.76	
	3	2.95	1.19	1.95	
	4	56.50	1.93	3.88	Moderated weathered phyllite
	5	8.02	5.64	9.52	High wethered phyllite
	6	339.00			Fresh phyllite

3. VES Line 3 interpretation results

Table A.3-1. 1st lateritic topsoil layer consisting of clayey sand and gravel which is 3.17 meters thick, 2nd high weathered phyllite layer is 11.88 meters thick, 3rd fresh phyllite layer 7.94 meters thick, 4th moderated weathered phyllite layer is 5.28 meters thick, 5th high weathered phyllite layer is 35.40 meters thick, and 6th fresh phyllite layer.

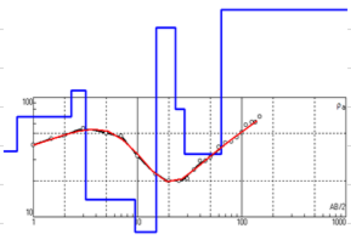
Apparent resistivity curve VES3-1	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	35.30	0.70	0.70	Topsoil
	2	68.90	1.61	2.31	
	3	115.00	0.86	3.17	
	4	14.00	6.36	9.53	High wethered phyllite
	5	7.50	5.52	15.05	
	6	383.00	7.94	22.99	Fresh phyllite
	7	80.10	5.28	28.27	Moderated weathered phyllite
	8	33.50	35.40	63.67	High wethered phyllite
	9	1639.00			Fresh phyllite

Table A.3-2. 1st lateritic topsoil layer consisting of sandy clay and gravel and underlying clay or high weathered phyllite which is 5.35 meters thick, 2ndfresh phyllite or laterite layeris 2.86 meters thick, 3rdmoderated weathered phyllite layer 6.68 meters thick, 4thhigh weathered phyllite layer is 23.20 meters thick, and 5thfresh phyllite layer.

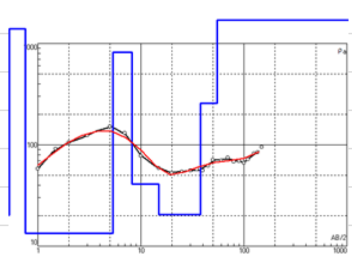
Apparent resistivity curve VES3-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	20.20	0.29	0.29	Topsoil
	2	1390.00	0.46	0.75	
	3	13.40	4.60	5.35	
	4	817.00	2.86	8.21	laterite / Fresh phyllite
	5	41.10	6.68	14.89	Moderated weathered phyllite
	6	20.40	23.20	38.09	High wethered phyllite
	7	258.00	17.00	55.09	Fresh phyllite
	8	2607.00			

Table A.3-3. 1st lateritic topsoil layer consisting of sandy clay and gravel which is 1.98 meters thick, 2nd fresh phyllite or laterite layer is 3.04 meters thick, 3rd moderated weathered phyllite layer 5.15 meters thick, 4th fresh phyllite layer is 9.31 meters thick, 5th high weathered phyllite layer is 20.50 meters thick, and 6th fresh phyllite layer.

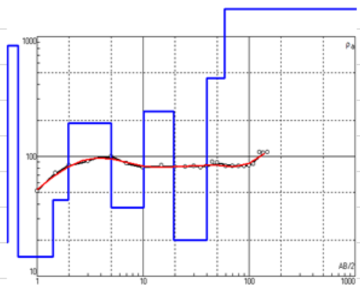
Apparent resistivity curve VES3-3	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	19.20	0.31	0.31	Topsoil
	2	844.00	0.35	0.66	
	3	14.60	0.75	1.41	
	4	43.40	0.56	1.98	
	5	189.00	3.04	5.02	laterite / Fresh phyllite
	6	37.20	5.15	10.17	Moderated weathered phyllite
	7	238.00	9.31	19.48	Fresh phyllite
	8	20.10	20.50	39.98	High wethered phyllite
	9	449.00	18.60	58.58	Fresh phyllite
	10	3730.00			

Table A.3-4. 1st lateritic topsoil layer consisting of sandy clay and gravel which is 2.65 meters thick, 2nd moderated weathered phyllite layer is 4.06 meters thick, 3rd fresh phyllite layer 13.40 meters thick, 4th high weathered phyllite layer is 19.30 meters thick, 5th fresh phyllite layer.

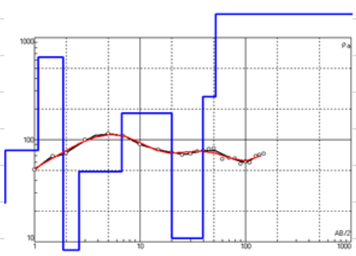
Apparent resistivity curve VES3-4	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	24.10	0.26	0.26	Topsoil
	2	78.20	0.83	1.09	
	3	642.00	0.79	1.88	
	4	8.27	0.77	2.65	
	5	48.80	4.06	6.71	Moderated weathered phyllite
	6	181.00	13.40	20.11	Fresh phyllite
	7	10.80	19.30	39.41	High wethered phyllite
	8	264.00	13.00	52.41	Fresh phyllite
	9	10750.00			

Table A.3-5. 1st lateritic topsoil layer consisting of sandy clay and gravel and underlying laterite which is 4.55 meters thick, 2nd high weathered phyllite layer 18.10 meters thick, 3rdfresh phyllite layer is 21.23 meters thick, 4th moderated weathered phyllite layer is 34.30 meters thick, and 5th fresh phyllite layer.

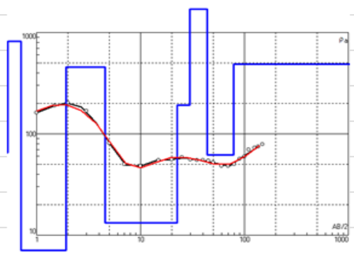
Apparent resistivity curve VES3-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	65.10	0.26	0.26	Topsoil
	2	821.00	0.45	0.71	
	3	7.05	1.20	1.91	
	4	455.00	2.64	4.55	
	5	13.30	18.10	22.65	High wethered phyllite
	6	192.00	7.33	29.98	Fresh phyllite
	7	2558.00	13.90	43.88	
	8	61.60	34.30	78.18	Moderated weathered phyllite
	9	485.00			Fresh phyllite

Table A.3-6. 1st lateritic topsoil layer consisting of sandy gravel and underlying laterite which is 2.64 meters thick, 2nd high weathered phyllite layer 2.32 meters thick, 3rd moderated weathered phyllite layer is 3.74 meters thick, 4th high weathered phyllite layer is 7.29 meters thick, 5th moderated phyllite layer is 46.44 meters thick, and 6th fresh phyllite layer.

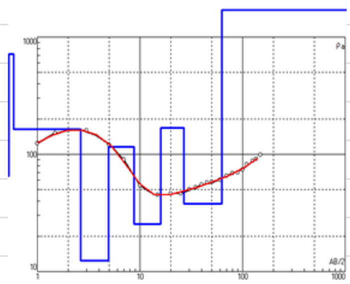
Apparent resistivity curve VES3-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	65.17	0.37	0.37	Topsoil
	2	715.30	0.21	0.58	
	3	163.40	2.06	2.64	
	4	12.37	2.32	4.96	High wethered phyllite
	5	116.00	3.74	8.70	Moderated weathered phyllite
	6	25.34	7.29	15.98	High wethered phyllite
	7	168.10	10.74	26.72	Moderated weathered phyllite
	8	37.63	35.70	62.42	
	9	2788.00			Fresh phyllite

Table A.3-7. 1st lateritic topsoil layer consisting of clay and gravel which is 2.60 meters thick, 2nd fresh phyllite/or laterite layer 6.49 meters thick, 3rd high weathered phyllite layer is 12.20 meters thick, 4th fresh phyllite layer is 12.80 meters thick, 5th high phyllite layer is 22.10 meters thick, 6thmoderated weathered phyllite layer is 27.20 meters thick, and 7th fresh phyllite layer.

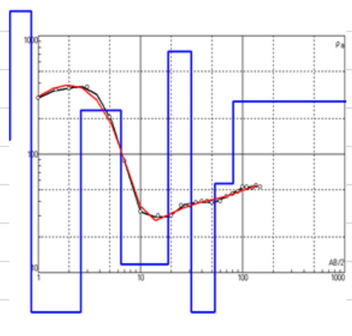
Apparent resistivity curve VES3-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	132.00	0.31	0.31	Topsoil
	2	1616.00	0.54	0.86	
	3	4.17	1.74	2.60	
	4	235.00	3.89	6.49	Fresh phyllite
	5	11.70	12.20	18.69	High wethered phyllite
	6	734.00	12.80	31.49	Fresh phyllite
	7	1.57	22.10	53.59	High wethered phyllite
	8	56.20	27.20	80.79	Moderated weathered phyllite
	9	277.00			Fresh phyllite

Table A.3-8. 1st lateritic topsoil layer consisting of sand and gravel and underlying clay which is 2.59 meters thick, 2nd moderated weathered phyllite layer 16.85 meters thick, 3rd high weathered phyllite layer is 18.40 meters thick, and 4th fresh phyllite layer.

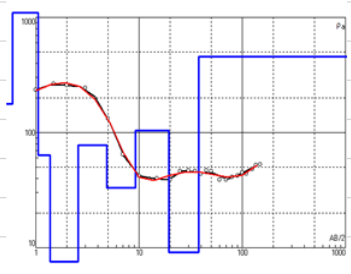
Apparent resistivity curve VES3-8	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	178.00	0.60	0.60	Topsoil
	2	1096.00	0.46	1.06	
	3	63.20	0.33	1.39	
	4	7.56	1.20	2.59	
	5	77.30	2.30	4.89	Moderated weathered phyllite
	6	33.30	4.35	9.24	
	7	104.00	10.20	19.44	
	8	9.08	18.40	37.84	High wethered phyllite
	9	458.00			Fresh phyllite

Table A.3-9. 1st lateritic topsoil layer consisting of sand and gravel and underlying sandy clay which is 3.44 meters, 2nd high weathered phyllite layer 4.64 meters thick, 3rd moderated weathered phyllite layer is 7.70 meters thick, 4th high weathered phyllite layer is 24.30 meters thick, 5th fresh phyllite layer.

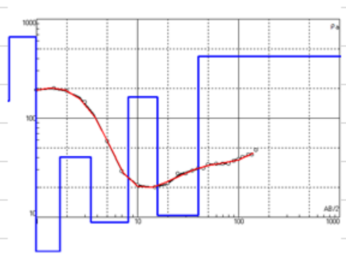
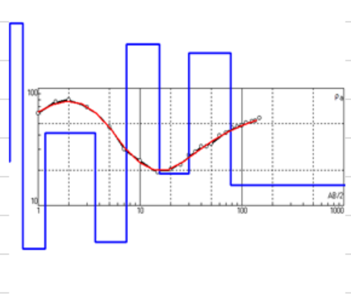
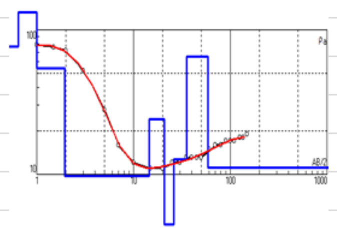
Apparent resistivity curve VES3-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	150.00	0.54	0.54	Topsoil
	2	661.00	0.45	0.98	
	3	4.50	0.71	1.70	
	4	40.20	1.74	3.44	
	5	8.87	4.64	8.08	High wethered phyllite
	6	164.00	7.70	15.78	Moderated weathered phyllite
	7	10.40	24.30	40.08	High wethered phyllite
	8	421.00			Fresh phyllite

Table A.3-10. 1st lateritic topsoil layer consisting of sand and gravel which is 3.62 meters thick, 2nd high weathered phyllite layer 3.79 meters thick, 3rd fresh phyllite layer is 8.18 meters thick, 4th high weathered phyllite layer is 14.40 meters thick, 5th fresh phyllite layer is 47.50 meters thick, 6th high weathered phyllite.



Apparent resistivity curve VES3-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	23.90	0.27	0.27	Topsoil
	2	360.00	0.44	0.71	Topsoil
	3	4.25	0.46	1.18	Topsoil
	4	41.30	2.44	3.62	Topsoil
	5	4.90	3.79	7.41	High wethered phyllite
	6	238.00	8.18	15.59	Fresh phyllite
	7	18.70	14.40	29.99	High wethered phyllite
	8	201.00	47.50	77.49	Fresh phyllite
	9	14.90			High wethered phyllite

Table A.3-11. 1st lateritic topsoil layer consisting of sand and gravel which is 1.95 meters thick, 2nd high weathered phyllite layer 33.38 meters thick, 3rd moderated weathered phyllite layer is 23.73 meters thick, 4th high weathered phyllite layer.



Apparent resistivity curve VES3-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	76.21	0.65	0.65	Topsoil
	2	132.10	0.35	1.00	Topsoil
	3	53.87	0.95	1.95	Topsoil
	4	9.75	12.53	14.48	High wethered phyllite
	5	24.05	6.40	20.88	High wethered phyllite
	6	4.51	5.08	25.96	High wethered phyllite
	7	12.74	9.38	35.33	High wethered phyllite
	8	65.03	23.73	59.06	Moderated weathered phyllite
	9	11.07			High wethered phyllite

Table A.3-12. 1st lateritic topsoil layer consisting of clay and gravel which is 2.53 meters thickness, 2nd high weathered phyllite layer is 7.21 meters thick, 3rd moderated weathered phyllite layer is 11.50 meters thick, 4th high weathered phyllite layer is 23.20 meters thick, and 5th fresh phyllite layer.

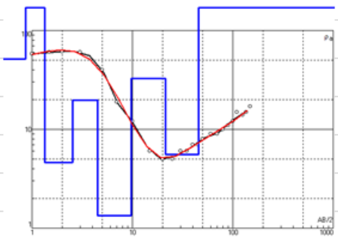
Apparent resistivity curve VES3-12	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	51.70	0.87	0.87	Topsoil
	2	249.00	0.48	1.35	
	3	4.61	1.18	2.53	
	4	19.60	1.98	4.51	High wethered phyllite
	5	1.34	5.23	9.74	
	6	32.50	11.50	21.24	Moderated weathered phyllite
	7	5.58	24.20	45.44	High wethered phyllite
	8	463.00			Fresh phyllite

Table A.3-13. 1st lateritic topsoil layer consisting of clay and gravel which is 1.52 meters thick, 2nd high weathered phyllite layer is 6.32 meters thick, 3rd moderated weathered phyllite layer is 4.60 meters thick, 4th high weathered phyllite layer is 10.90 meters thick, and 5th fresh phyllite layer.

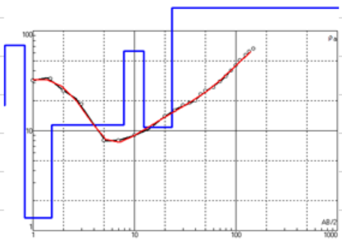
Apparent resistivity curve VES3-13	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	18.00	0.26	0.26	Topsoil
	2	71.70	0.57	0.83	
	3	1.34	0.69	1.52	
	4	11.40	6.32	7.84	High wethered phyllite
	5	62.50	4.60	12.44	Moderated weathered phyllite
	6	10.80	10.90	23.34	High wethered phyllite
	7	182.00	9.88	33.22	Fresh phyllite
	8	7016.00			

Table A.3-14. 1st lateritic topsoil layer consisting of sand and gravel which is 1.40 meters thick, 2nd high weathered phyllite layer is 2.26 meters thick, 3rd fresh phyllite layer is 2.23 meters thick, 4th high weathered phyllite layer is 16.50 meters thick, and 5th fresh phyllite layer.

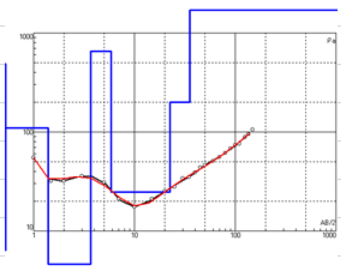
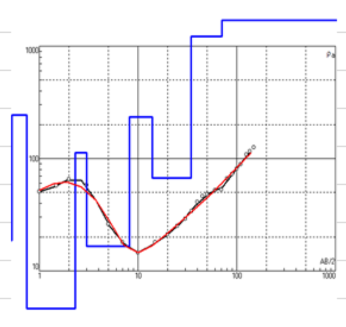
Apparent resistivity curve VES3-14	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	486.00	0.27	0.27	Topsoil
	2	6.39	0.21	0.48	
	3	110.00	0.92	1.40	
	4	3.58	2.26	3.66	High wethered phyllite
	5	657.00	2.23	5.89	Fresh phyllite
	6	24.70	16.50	22.39	High wethered phyllite
	7	200.00	12.90	35.29	Fresh phyllite
	8	4881.00			

Table A.3-15. 1st lateritic topsoil layer consisting of clay and gravel which is 2.30 meters thick, 2nd moderated weathered phyllite layer is 0.72 meters thick, 3rd high weathered phyllite layer is 5.14 meters thick, 4th fresh phyllite layer is 5.82 meters thick, 5th moderated weathered phyllite layer is 20.40 meters thick, 6th fresh phyllite layer.

Apparent resistivity curve VES3-15	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	18.80	0.25	0.25	Topsoil
	2	245.00	0.51	0.75	
	3	2.93	1.55	2.30	
	4	113.00	0.72	3.02	Moderated weathered phyllite
	5	16.60	5.14	8.16	High wethered phyllite
	6	233.00	5.82	13.98	Fresh phyllite
	7	67.20	20.40	34.38	Moderated weathered phyllite
	8	1229.00	36.40	70.78	Fresh phyllite
	9	6706.00			

4. VES Line 4 interpretation results

Table A.4-1. 1st lateritic topsoil layer consisting of clay and gravel which is 2.51 meters thick, 2nd laterite or/and fresh phyllite layer is 4.02 meters thick, 3rd high weathered phyllite layer is 14.30 meters thick, 4th moderated weathered phyllite layer is 12.50 meters thick, and 5th fresh phyllite layer.

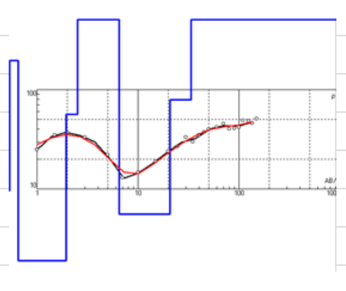
Apparent resistivity curve VES4-1	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description	
	1	9.66	0.25	0.25	Topsoil	
	2	197.00	0.39	0.65		
	3	1.88	1.29	1.94		
	4	56.10	0.57	2.51		
	5	545.00	4.02	6.53	laterite	Fresh phyllite
	6	5.57	14.30	20.83	High wethered phyllite	
	7	79.00	12.50	33.33	Moderated weathered phyllite	
	8	881.00			Fresh phyllite	

Table A.4-2. 1st lateritic topsoil layer consisting of clay and gravel which is 2.10 meters thick, 2nd clay or high weathered phyllite layer is 2.18 meters thick, 3rd laterite or fresh phyllite layer is 4.39 meters thick, 4th high weathered phyllite layer is 14.27 meters thick, 5th moderated weathered phyllite layer is 8.81 meters thick, and 6th fresh phyllite layer.

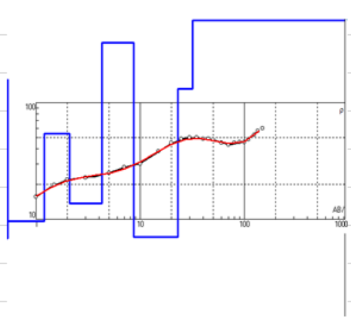
Apparent resistivity curve VES4-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	6.82	0.32	0.32	Topsoil
	2	158.10	0.19	0.51	
	3	9.56	0.69	1.20	
	4	54.13	0.90	2.10	
	5	13.59	2.18	4.28	High wethered phyllite
	6	324.60	4.39	8.67	laterite / Fresh phyllite
	7	7.02	14.27	22.93	High wethered phyllite
	8	131.70	8.81	31.74	Moderated weathered phyllite
	9	1905.00			Fresh phyllite

Table A.4-3. 1st lateritic topsoil layer consisting of clayey sand and underlying sandy clay which is 1.74 meters thick, 2nd laterite or fresh phyllite layer is 1.69 meters thick, 3rd high weathered phyllite layer is 5.39 meters thick, 4th moderated weathered phyllite layer is 14.90 meters thick, 5th high weathered phyllite layer is 15.30 meters thick, 6th moderated weathered phyllite layer is 15.40 meters thick, and 7th fresh phyllite layer.

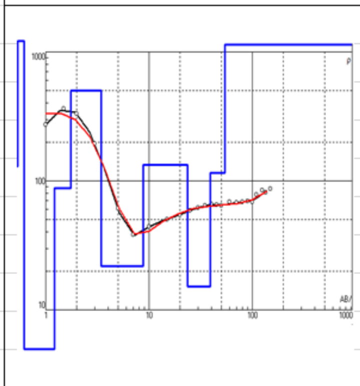
Apparent resistivity curve VES4-3	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	130.00	0.22	0.22	Topsoil
	2	1216.00	0.40	0.62	
	3	3.37	0.60	1.22	
	4	87.80	0.52	1.74	
	5	502.00	1.69	3.43	laterite / Fresh phyllite
	6	21.70	5.39	8.82	High wethered phyllite
	7	133.00	14.90	23.72	Moderated weathered phyllite
	8	15.20	15.30	39.02	High wethered phyllite
	9	116.00	15.40	54.42	Moderated weathered phyllite
	10	1143.00			Fresh phyllite

Table A.4-4. 1st lateritic topsoil layer consisting of clay and gravel which is 0.54 meters thick, 2nd sand and gravel or/and moderated weathered phyllite layer is 4.77 meters thick, 3rd high weathered phyllite layer is 3.15 meters thick, 4th moderated weathered phyllite layer is 16.42 meters thick, 5th high weathered phyllite layer is 19.55 meters thick, 6th moderated weathered phyllite layer is 25.56 meters thick, and 7th fresh phyllite layer.

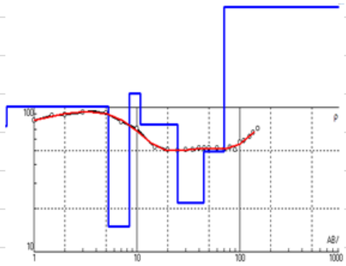
Apparent resistivity curve VES4-4	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	73.67	0.54	0.54	Topsoil
	2	101.40	4.77	5.31	Moderated weathered phyllite
	3	14.93	3.15	8.45	High wethered phyllite
	4	124.50	2.40	10.85	Moderated weathered phyllite
	5	76.04	14.02	24.87	
	6	21.78	19.55	44.42	High wethered phyllite
	7	49.80	25.56	69.98	Moderated weathered phyllite
	8	493.50			Fresh phyllite

Table A.4-5. 1st lateritic topsoil layer consisting of gravelly clay and underlying gravel or moderated weathered phyllite layer which is 2.85 meters thickness, 2nd high weathered phyllite layer is 3.74 meters thick, 3rd fresh phyllite layer is 6.19 meters thick, 4th high weathered phyllite layer is 22.70 meters thick, and 5th fresh phyllite layer.

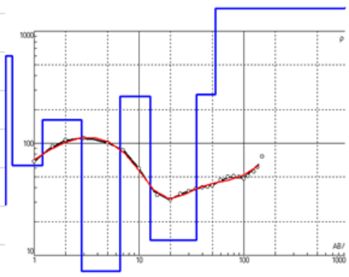
Apparent resistivity curve VES4-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	28.20	0.31	0.31	Topsoil
	2	603.00	0.31	0.62	
	3	63.40	0.58	1.21	
	4	161.00	1.64	2.85	
	5	7.22	3.74	6.59	High wethered phyllite
	6	261.00	6.19	12.78	Fresh phyllite
	7	13.60	22.70	35.48	High wethered phyllite
	8	273.00	18.10	53.58	Fresh phyllite
	9	4958.00			

Table A.4-6. 1st lateritic topsoil layer consisting of clay and gravel which is 1.74 meters thick, 2nd laterite or fresh phyllite layer is 3.23 meters thick, 3rd high weathered phyllite layer is 1.80 meters thick, 4th moderated weathered phyllite layer is 9.20 meters thick, 5th high weathered phyllite layer is 18.30 meters thick, and 6th fresh phyllite layer.

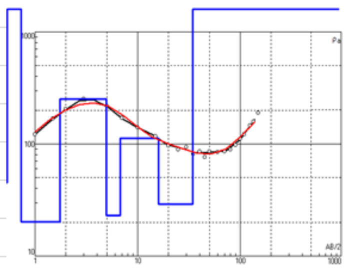
Apparent resistivity curve VES4-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	45.10	0.30	0.30	Topsoil
	2	1894.00	0.43	0.73	
	3	20.10	1.01	1.74	
	4	253.00	3.23	4.97	Fresh phyllite
	5	23.00	1.80	6.77	High wethered phyllite
	6	112.00	9.20	15.97	Moderated weathered phyllite
	7	28.90	18.30	34.27	High wethered phyllite
	8	5623.00			Fresh phyllite

Table A.4-7. 1st lateritic topsoil layer consisting of sand and gravel and underlying clay or high weathered phyllite which is 2.73 meters thick, 2nd laterite or fresh phyllite layer is 3.86 meters thick, 3rd high weathered phyllite layer is 6.76 meters thick, 4th fresh phyllite layer is 28.80 meters thick, 5th high weathered phyllite layer is 25.40 meters thick, and 6th fresh phyllite layer.

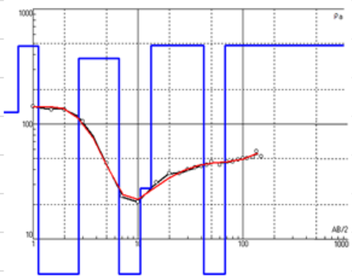
Apparent resistivity curve VES4-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	127.00	0.72	0.72	Topsoil
	2	478.00	0.40	1.12	
	3	3.92	1.61	2.73	
	4	374.00	3.86	6.59	Fresh phyllite
	5	3.03	3.92	10.51	High wethered phyllite
	6	27.60	2.84	13.35	
	7	483.00	28.80	42.15	Fresh phyllite
	8	4.01	25.40	67.55	High wethered phyllite
	9	483.00			Fresh phyllite

Table A.4-8. 1st lateritic topsoil layer consisting of clay and gravel which is 0.76 meters thick, 2nd clay or/and high weathered phyllite layer is 7.44 meters thick, 3rd fresh phyllite layer is 4.62 meters thick, 4th high weathered phyllite layer is 9.52 meters thick, 5th moderated weathered phyllite layer is 8.57 meters thick, and 6th fresh phyllite layer.

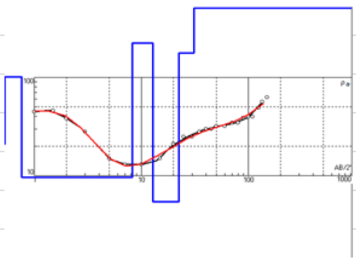
Apparent resistivity curve VES4-8	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	21.00	0.22	0.22	Topsoil
	2	101.00	0.54	0.76	
	3	9.59	7.44	8.20	Clay/High wethered phyllite
	4	223.00	4.62	12.82	Fresh phyllite
	5	5.40	9.52	22.34	High wethered phyllite
	6	177.00	8.57	30.91	Moderated weathered phyllite
	7	7997.00			Fresh phyllite

Table A.4-9 shows 1st lateritic topsoil layer consisting of gravelly clay which is 2.08 meters thick, 2nd clay or/and high weathered phyllite layer is 4.22 meters thicks, 3rd fresh phyllite layer is 3.58 meters thick, 4th high weathered phyllite layer is 14.60 meters thick, and 5th fresh phyllite layer.

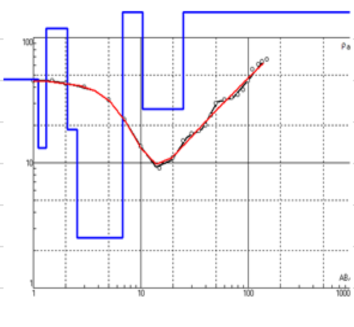
Apparent resistivity curve VES4-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	46.50	1.11	1.11	Topsoil
	2	13.10	0.21	1.32	
	3	119.00	0.76	2.08	
	4	18.40	0.47	2.55	
	5	2.51	4.22	6.77	High wethered phyllite
	6	1895.00	3.58	10.35	Fresh phyllite
	7	26.90	14.60	24.95	High wethered phyllite
	8	3197.00			Fresh phyllite

Table A.4-10. 1st lateritic topsoil layer consisting of sand and gravel and underlying clay which is 3.29 meters thick, 2nd moderated weathered phyllite layer is 1.07 meters thick, 3rd high weathered phyllite layer is 6.05 meters thick, 4th fresh phyllite layer is 9.85 meters thick, 5th high weathered phyllite layer is 23.70 meters thick, and 6th fresh phyllite layer.

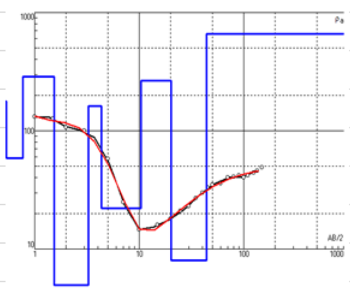
Apparent resistivity curve VES4-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	177.00	0.45	0.45	Topsoil
	2	58.50	0.32	0.77	
	3	285.00	0.76	1.54	
	4	2.31	1.75	3.29	
	5	162.00	1.07	4.36	Moderated weathered phyllite
	6	22.10	6.05	10.41	High wethered phyllite
	7	264.00	9.85	20.26	Fresh phyllite
	8	8.00	23.70	43.96	High wethered phyllite
	9	656.00			Fresh phyllite

Table A.4-11. 1st lateritic topsoil layer consisting of clay and gravel which is 2.68 meters thick, 2nd laterite or/ fresh phyllite layer is 2.71 meters thick, 3rd high weathered phyllite layer is 28.50 meters thick, and 4th fresh phyllite layer.

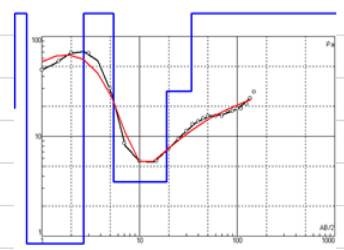
Apparent resistivity curve VES4-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description	
	1	19.30	0.24	0.24	Topsoil	
	2	293.00	0.46	0.70		
	3	0.84	1.98	2.68		
	4	452.00	2.71	5.39	laterite	Fresh phyllite
	5	3.48	13.50	18.89	High wethered phyllite	
	6	28.30	15.00	33.89		
	7	283.00			Fresh phyllite	

Table 4.4.4-12. 1st lateritic topsoil layer consisting of sand and gravel which is 2.62 meters thick, 2nd high weathered phyllite layer is 25.78 meters thick, 3rd fresh phyllite layer is 21.10 meters thick, and 4th high weathered phyllite layer.

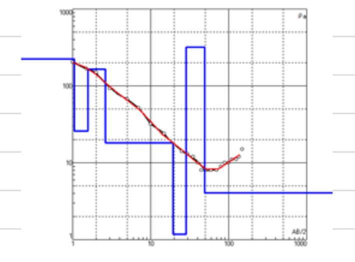
Apparent resistivity curve VES4-12	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	225.00	1.06	1.06	Topsoil
	2	25.90	0.52	1.58	
	3	165.00	1.04	2.62	
	4	18.30	16.60	19.22	High wethered phyllite
	5	1.17	9.18	28.40	
	6	320.00	21.10	49.50	Fresh phyllite
	7	4.06			High wethered phyllite

Table A.4-13. 1st lateritic topsoil layer consisting of sandy clay and underlying gravel which is 1.79 meters thick, 2nd high weathered phyllite layer is 42.86 meters thick, 3rd moderated weathered phyllite layer is 9.55 meters thick, and 4th fresh phyllite layer.

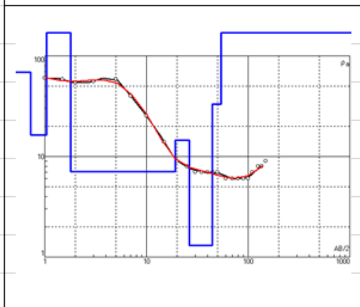
Apparent resistivity curve VES4-13	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	68.90	0.73	0.73	Topsoil
	2	16.40	0.32	1.04	
	3	274.00	0.75	1.79	
	4	7.10	17.30	19.09	High wethered phyllite
	5	14.60	7.46	26.55	
	6	1.31	18.10	44.65	
	7	33.00	9.55	54.20	Moderated weathered phyllite
	8	331.00			Fresh phyllite

Table A.4-14. 1st lateritic topsoil layer consisting of clay and gravel which is 3.03 meters thick, 2nd moderated weathered phyllite layer is 1.86 meters thick, 3rd high weathered phyllite layer is 5.22 meters thick, 4th moderated weathered phyllite layer is 2.01 meters thick, and 5th fresh phyllite layer.

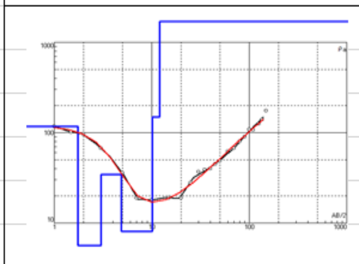
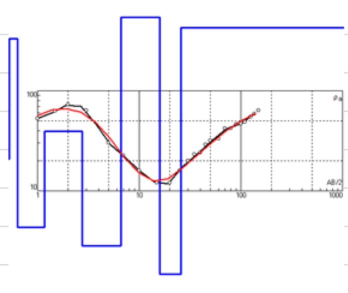
Apparent resistivity curve VES4-14	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	118.00	1.75	1.75	Topsoil
	2	5.67	1.28	3.03	
	3	34.60	1.86	4.89	Moderated weathered phyllite
	4	8.09	5.22	10.11	High wethered phyllite
	5	150.00	2.01	12.12	Moderated weathered phyllite
	6	4895.00			Fresh phyllite

Table A.4-15. 1st lateritic topsoil layer consisting of clay and gravel which is 2.76 meters thick, 2nd high weathered phyllite layer is 2.84 meters thick, 3rd fresh phyllite layer is 9.39 meters thick, 4th high weathered phyllite layer is 9.85 meters thick, and 5th fresh phyllite layer.

Apparent resistivity curve VES4-15	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	20.90	0.26	0.26	Topsoil
	2	330.00	0.38	0.63	
	3	4.30	0.53	1.17	
	4	39.40	1.59	2.76	
	5	2.84	3.85	6.61	High wethered phyllite
	6	1667.00	9.39	16.00	Fresh phyllite
	7	0.60	9.85	25.85	High wethered phyllite
	8	429.00			Fresh phyllite

5. VES Line 5 interpretation results

Table A.5-1. 1st lateritic topsoil layer consisting of unsaturated sand and gravel and underlying saturated clay which is 2.33 meters thick, 2nd laterite or fresh phyllite layer is 2.01 meters thick, 3rd high weathered phyllite layer is 5.97 meters thick, 4th moderated weathered phyllite layer is 8.08 meters thick, 5th high weathered phyllite layer is 25.34 meters thick, and 6th fresh phyllite layer.

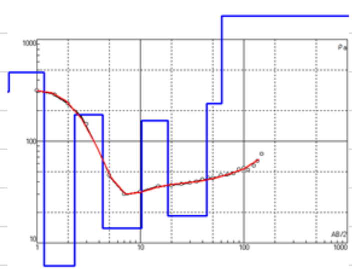
Apparent resistivity curve VES5-1	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	307.50	0.54	0.54	Topsoil
	2	475.80	0.63	1.17	
	3	5.96	1.16	2.33	
	4	181.40	2.01	4.34	Fresh phyllite
	5	14.00	5.97	10.31	High wethered phyllite
	6	160.00	8.08	18.39	Moderated weathered phyllite
	7	18.36	25.34	43.73	High wethered phyllite
	8	235.60	17.65	61.38	Fresh phyllite
	9	2265.00			

Table A.5-2. 1st lateritic topsoil layer consisting of clay and gravel and underlying laterite which is 3.87 meters thick, 2nd high weathered phyllite layer is 3.48 meters thick, 3rd fresh phyllite layer is 9.43 meters thick, 4th high weathered phyllite layer is 15.00 meters thick, and 5th fresh phyllite layer.

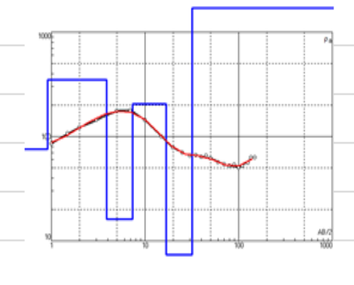
Apparent resistivity curve VES5-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	75.60	0.91	0.91	Topsoil
	2	348.00	2.96	3.87	
	3	16.20	3.48	7.35	High wethered phyllite
	4	204.00	9.43	16.78	Fresh phyllite
	5	7.34	15.00	31.78	High wethered phyllite
	6	3436.00			Fresh phyllite

Table A.5-3. 1st lateritic topsoil layer consisting of sand and gravel, and underlying laterite which is 2.07 meters thick, 2nd moderated weathered phyllite layer is 6.02 meters thick, 3rd high weathered phyllite layer is 4.02 meters thick, 4th moderated weathered phyllite layer is 9.57 meters thick, 5th high weathered phyllite layer is 18.90 meters thick, and 6th fresh phyllite layer.

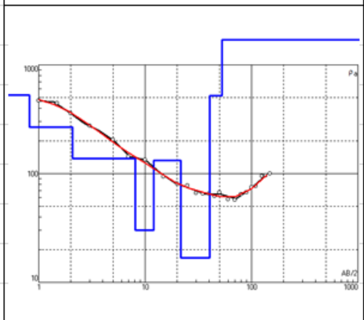
Apparent resistivity curve VES5-3	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	530.00	0.82	0.82	Topsoil
	2	267.00	1.25	2.07	
	3	137.00	6.02	8.09	Moderated weathered phyllite
	4	30.10	4.02	12.11	High wethered phyllite
	5	133.00	9.57	21.68	Moderated weathered phyllite
	6	16.70	18.90	40.58	High wethered phyllite
	7	521.00	12.20	52.78	Fresh phyllite
	8	4569.00			

Table A.5-4. 1st lateritic topsoil layer consisting of clay and gravel which is 2.82 meters thick, 2nd moderated weathered phyllite layer is 3.85 meters thick, 3rd high weathered phyllite layer is 7.46meters thick, 4th fresh phyllite layer is 40.80 meters thick, and 5th high weathered phyllite layer.

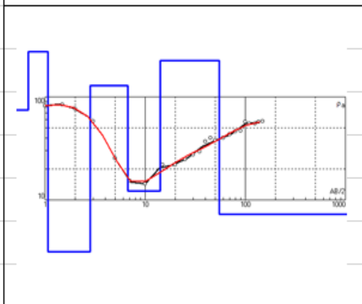
Apparent resistivity curve VES5-4	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	74.20	0.68	0.68	Topsoil
	2	276.00	0.39	1.07	
	3	3.15	1.75	2.82	
	4	128.00	3.85	6.67	Moderated weathered phyllite
	5	12.20	7.46	14.13	High wethered phyllite
	6	226.00	40.80	54.93	Fresh phyllite
	7	7.29			High wethered phyllite

Table A.5-5. 1st lateritic topsoil layer consisting of clay and gravel which is 2.40 meters thick, 2nd moderated weathered phyllite layer is 0.99 meters thick, 3rd fresh phyllite layer is 3.36 meters thick, 4th high weathered phyllite layer is 14.10 meters thick, 5th moderated weathered phyllite layer is 12.00 meters thick, 6th high weathered phyllite layer is 40.80 meters thick, and 7th fresh phyllite layer.

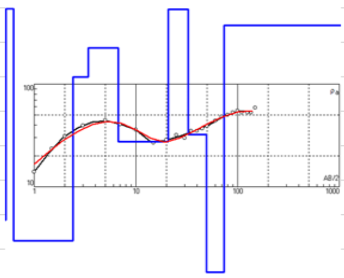
Apparent resistivity curve VES5-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	4.77	0.27	0.27	Topsoil
	2	647.00	0.36	0.63	
	3	2.96	1.77	2.40	
	4	117.00	0.99	3.39	Moderated weathered phyllite
	5	225.00	3.36	6.75	Fresh phyllite
	6	27.40	14.10	20.85	High wethered phyllite
	7	532.00	12.00	32.85	Moderated weathered phyllite
	8	32.20	16.50	49.35	High wethered phyllite
	9	1.31	24.30	73.65	
	10	373.00			Fresh phyllite

Table A.5-6. 1st lateritic topsoil layer consisting of clay and gravel which is 1.67 meters thick, 2nd high weathered phyllite layer is 5.64 meters thick, 3rd moderated weathered phyllite layer is 9.82 meters thick, 4th high weathered phyllite layer is 18.90 meters thick, and 5th fresh phyllite layer.

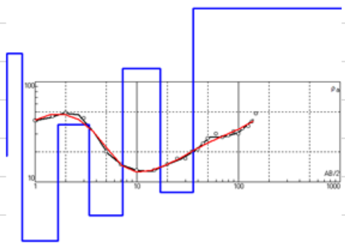
Apparent resistivity curve VES5-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	18.30	0.29	0.29	Topsoil
	2	193.00	0.45	0.75	
	3	2.57	0.93	1.67	
	4	37.20	1.73	3.40	High wethered phyllite
	5	4.61	3.91	7.31	
	6	136.00	9.82	17.13	Moderated weathered phyllite
	7	7.88	18.90	36.03	High wethered phyllite
	8	4701.00			Fresh phyllite

Table A.5-7. 1st lateritic sandy clay topsoil layer which is 2.54 meters thick, 2nd high weathered phyllite layer is 2.83 meters thick, 3rd moderated weathered phyllite layer is 6.53 meters thick, 4th high weathered phyllite layer is 16.60 meters thick, and 5th fresh phyllite layer.

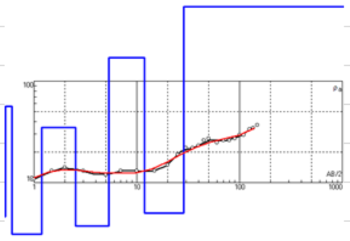
Apparent resistivity curve VES5-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	4.63	0.28	0.28	Topsoil
	2	56.20	0.33	0.61	
	3	3.09	0.58	1.19	
	4	34.80	1.35	2.54	
	5	3.71	2.83	5.37	High wethered phyllite
	6	170.00	6.53	11.90	Moderated weathered phyllite
	7	5.03	16.60	28.50	High wethered phyllite
	8	4791.00			Fresh phyllite

Table A.5-8. 1st lateritic topsoil layer consisting of clay and gravel and underlying clay which is 2.84 meters thick, 2nd high weathered phyllite layer is 1.07 meters thick, 3rd fresh phyllite layer is 5.38 meters thick, 4th high weathered phyllite layer is 15.20 meters thick, 5th moderated weathered phyllite layer is 8.55 meters thick, and 6th fresh phyllite.

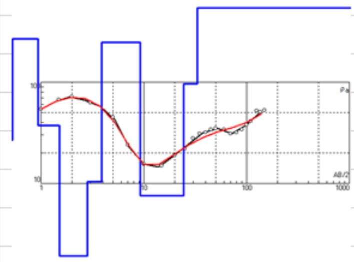
Apparent resistivity curve VES5-8	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	26.60	0.36	0.36	Topsoil
	2	266.00	0.57	0.93	
	3	37.50	0.58	1.51	
	4	1.92	1.33	2.84	
	5	10.40	1.07	3.91	High wethered phyllite
	6	246.00	5.38	9.29	Fresh phyllite
	7	7.52	15.20	24.49	High wethered phyllite
	8	96.00	8.55	33.04	Moderated weathered phyllite
	9	1622.00			Fresh phyllite

Table A.5-9. 1st lateritic topsoil layer consisting of clayey sand and underlying clay which is 3.18 meters thick, 2nd moderated weathered phyllite layer is 1.90 meters thick, 3rd high weathered phyllite layer is 62.50 meters thick, and 4th moderated weathered phyllite layer.

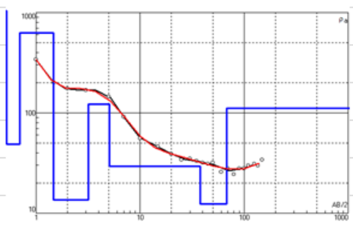
Apparent resistivity curve VES5-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	1043.00	0.38	0.38	Topsoil
	2	48.80	0.32	0.70	
	3	625.00	0.77	1.47	
	4	13.50	1.71	3.18	
	5	122.00	1.90	5.08	Moderated weathered phyllite
	6	29.20	32.90	37.98	High wethered phyllite
	7	12.40	29.60	67.58	
	8	111.00			Moderated weathered phyllite

Table A.5-10. 1st lateritic topsoil layer consisting of clay and gravel which is 0.77 meters thick, 2nd clay or/and high weathered phyllite layer is 15.73 meters thick, 3rd fresh phyllite layer is 10.70 meters thick, 4th high weathered phyllite layer is 11.60 meters thick, and 5th moderated weathered phyllite layer.

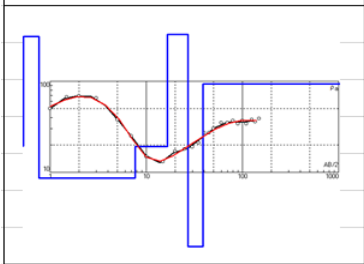
Apparent resistivity curve VES5-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	19.50	0.27	0.27	Topsoil
	2	308.00	0.50	0.77	
	3	8.60	6.86	7.63	High wethered phyllite
	4	19.30	8.87	16.50	
	5	325.00	10.70	27.20	Fresh phyllite
	6	1.54	11.60	38.80	High wethered phyllite
	7	93.80			Moderated weathered phyllite

Table A.5-11. 1st lateritic topsoil layer consisting of clay and gravel which is 0.70 meters thick, 2nd clay or high weathered phyllite layer is 1.54 meters thick, 3rdmoderated weathered phyllite layer is 0.68 meters thick, 4th fresh phyllite layer is 2.83 meters thick, 5th high weathered phyllite layer is 14.80 meters thick, and 6th fresh phyllite layer.

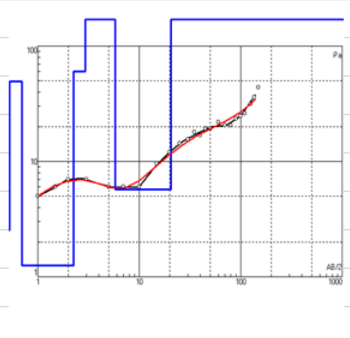
Apparent resistivity curve VES5-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	2.54	0.40	0.40	Topsoil
	2	49.60	0.30	0.70	
	3	1.25	1.54	2.24	High wethered phyllite
	4	60.50	0.68	2.92	Moderated weathered phyllite
	5	333.00	0.81	3.74	Fresh phyllite
	6	190.00	2.02	5.76	
	7	5.72	14.80	20.56	High wethered phyllite
	8	273.00	26.60	47.16	Fresh phyllite
	9	1887.00			

Table A.5-12. 1st lateritic topsoil layer consisting of sand and gravel which is 2.04 meters thick, 2nd clay or/and high weathered phyllite layer is 1.17 meters thick, 3rd moderated weathered phyllite layer is 2.60 meters thick, 4th high weathered phyllite layer is 69.04 meters thick, and 5th moderated weathered phyllite layer.

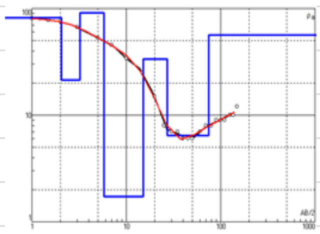
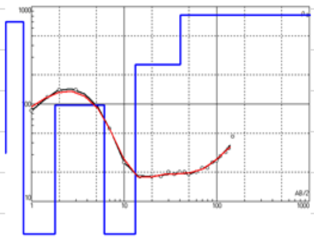
Apparent resistivity curve VES5-12	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	81.50	2.04	2.04	Topsoil
	2	21.30	1.17	3.21	High wethered phyllite
	3	90.70	2.60	5.81	Moderated weathered phyllite
	4	1.72	9.34	15.15	
	5	33.40	12.10	27.25	High wethered phyllite
	6	6.47	47.60	74.85	
	7	56.30			Moderated weathered phyllite

Table A.5-13. 1st lateritic topsoil layer consisting of clay and gravel which is 1.80 meters thick, 2nd moderated weathered phyllite layer is 4.32 meters thick, 3rd high weathered phyllite layer is 7.12 meters thick, and 4th fresh phyllite layer.

Apparent resistivity curve VES5-13	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	31.50	0.26	0.26	
	2	695.00	0.56	0.82	Topsoil
	3	1.53	0.98	1.80	
	4	97.30	4.32	6.12	Moderated weathered phyllite
	5	2.48	7.12	13.24	High wethered phyllite
	6	253.00	27.10	40.34	Fresh phyllite
	7	817.00			

6. VES Line 6 interpretation results

Table A.6-1. 1st lateritic topsoil layer consisting of clay and gravel and underlying laterite which is 3.94 meters thick, 2nd high weathered phyllite layer is 3.75 meters thick, 3rd moderated weathered phyllite layer is 8.93 meters thick, 4th high weathered phyllite layer is 13.60 meters thick, 5th fresh phyllite layer is 32.90 meters thick, and 6th high weathered phyllite layer.

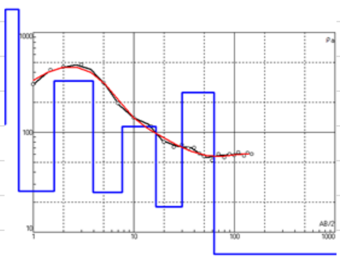
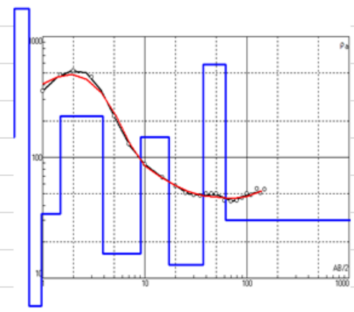
Apparent resistivity curve VES6-2	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	121.00	0.28	0.28	
	2	2594.00	0.44	0.72	Topsoil
	3	25.80	0.89	1.61	
	4	327.00	2.33	3.94	
	5	24.90	3.75	7.69	High wethered phyllite
	6	115.00	8.93	16.62	Moderated weathered phyllite
	7	17.90	13.60	30.22	High wethered phyllite
	8	250.00	32.90	63.12	Fresh phyllite
	9	6.02			High wethered phyllite

Table A.6-2. 1st lateritic topsoil layer consisting of clay and gravel and underlying laterite which is 3.91 meters thick, 2nd high weathered phyllite layer is 5.23 meters thick, 3rd moderated weathered phyllite layer is 8.15 meters thick, 4th high weathered phyllite layer is 19.90 meters thick, 5th fresh phyllite layer is 25.00 meters thick, and 6th high weathered phyllite layer.

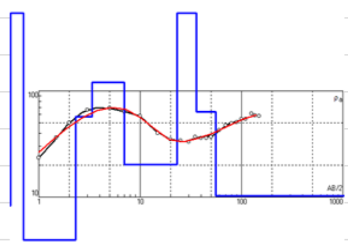
Apparent resistivity curve VES6-3



ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
1	147.00	0.26	0.26	Topsoil
2	2086.00	0.49	0.74	
3	5.87	0.24	0.98	
4	34.10	0.51	1.49	
5	220.00	2.42	3.91	
6	15.90	5.23	9.14	High wethered phyllite
7	148.00	8.15	17.29	Moderated weathered phyllite
8	12.80	19.90	37.19	High wethered phyllite
9	549.00	25.00	42.29	Fresh phyllite
10	30.20			High wethered phyllite

Table A.6-3 1st lateritic topsoil layer consisting of clay and gravel which is 2.30 meters thick, 2nd moderated weathered phyllite layer is 4.70 meters thick, 3rd high weathered phyllite layer is 16.10 meters thick, 4th fresh phyllite layer is 12.70 meters thick, 5th moderated weathered phyllite layer is 19.90 meters thick, and 6th high weathered phyllite layer.

Apparent resistivity curve VES6-4



ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
1	8.27	0.29	0.29	Topsoil
2	950.00	0.41	0.70	
3	3.94	1.60	2.30	
4	57.00	1.04	3.34	Moderated weathered phyllite
5	121.00	3.66	7.00	
6	20.30	16.10	23.10	High wethered phyllite
7	660.00	12.70	35.80	Fresh phyllite
8	63.70	19.90	55.70	Moderated weathered phyllite
9	10.30			High wethered phyllite

Table A.4-4 1st lateritic topsoil layer consisting of clay and gravel which is 2.29 meters thick, 2nd high weathered phyllite layer is 7.64 meters thick, 3rd fresh phyllite layer is 12.02 meters thick, 4th moderated weathered phyllite layer is 10.30 meters thick, 5th high weathered phyllite layer is 14.60 meters thick, and 6th fresh phyllite layer.

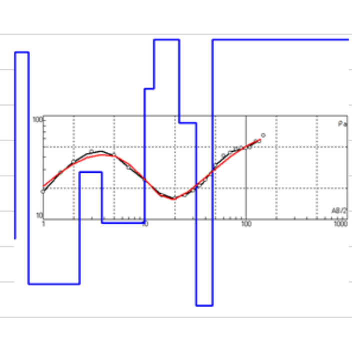
Apparent resistivity curve VES6-5	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	6.56	0.28	0.28	Topsoil
	2	412.00	0.44	0.72	
	3	2.38	1.57	2.29	
	4	28.50	1.50	3.79	High wethered phyllite
	5	9.20	6.14	9.93	
	6	183.00	2.50	12.43	Fresh phyllite
	7	1257.00	9.52	21.95	
	8	85.70	10.30	32.25	Moderated weathered phyllite
	9	0.70	14.60	46.85	High wethered phyllite
	10	579.00			Fresh phyllite

Table A.6-5 1st lateritic topsoil layer consisting of clay and gravel which is 2.85 meters thick, 2nd high weathered phyllite layer is 3.64 meters thick, 3rd moderated weathered phyllite layer is 7.59 meters thick, 4th high weathered phyllite layer is 15.90 meters thick, and 5th fresh phyllite layer.

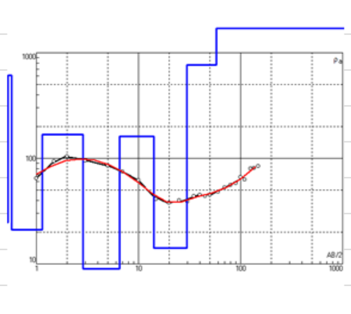
Apparent resistivity curve VES6-6	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	24.80	0.27	0.27	Topsoil
	2	614.00	0.31	0.57	
	3	21.20	0.57	1.14	
	4	167.00	1.71	2.85	
	5	9.03	3.64	6.49	High wethered phyllite
	6	161.00	7.59	14.08	Moderated weathered phyllite
	7	14.10	15.90	29.98	High wethered phyllite
	8	769.00	27.80	57.78	Fresh phyllite
	9	2957.00			

Table A.6-6. 1st lateritic topsoil layer consisting of clayey sand and gravel which is 2.15 meters thick, 2nd high weathered phyllite layer is 2.17 meters thick, 3rd moderated weathered phyllite layer is 6.14 meters thick, 4th high weathered phyllite layer is 18.70 meters thick, and 5th fresh phyllite layer.

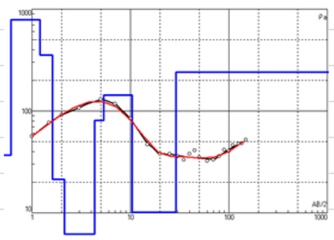
Apparent resistivity curve VES6-7	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	36.80	0.62	0.62	Topsoil
	2	783.00	0.59	1.20	
	3	354.00	0.41	1.61	
	4	21.30	0.54	2.15	
	5	6.21	2.17	4.32	High wethered phyllite
	6	80.40	1.02	5.34	Moderated weathered phyllite
	7	143.00	5.12	10.46	
	8	10.10	18.70	29.16	High wethered phyllite
	9	241.00			Fresh phyllite

Table A.6-7. 1st lateritic topsoil layer consisting of clay and gravel which is 1.37 meters thick, 2nd high weathered phyllite layer is 11.24 meters thick, 3rd moderated weathered phyllite layer is 10.30 meters thick, 4th high weathered phyllite layer is 25.00 meters thick, 5th moderated weathered phyllite layer is 11.80 meters thick, and 6th fresh phyllite layer.

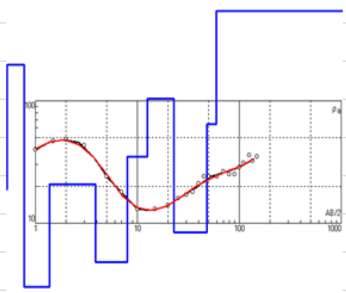
Apparent resistivity curve VES6-9	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	19.00	0.32	0.32	Topsoil
	2	198.00	0.45	0.78	
	3	3.03	0.60	1.37	
	4	20.80	2.49	3.86	High wethered phyllite
	5	4.79	4.08	7.94	
	6	34.80	4.67	12.61	
	7	104.00	10.30	22.91	Moderated weathered phyllite
	8	8.38	25.00	47.91	High wethered phyllite
	9	64.40	11.80	59.71	Moderated weathered phyllite
	10	1023.00			Fresh phyllite

Table A.6-8. 1st lateritic topsoil layer consisting of sandy clay and gravel which is 1.68 meters thick, 2nd moderated weathered phyllite layer is 6.39 meters thick, 3rd high weathered phyllite layer is 33.30 meters thick, 4th moderated weathered phyllite layer is 11.70 meters thick, and 5th fresh phyllite layer.

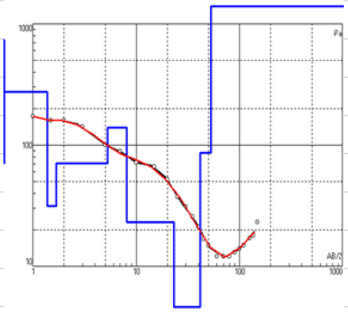
Apparent resistivity curve VES6-10	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	736.00	0.24	0.24	Topsoil
	2	70.90	0.26	0.50	
	3	275.00	0.88	1.37	
	4	31.50	0.30	1.68	
	5	70.60	3.63	5.31	Moderated weathered phyllite
	6	139.00	2.76	8.07	
	7	23.20	15.20	23.27	High wethered phyllite
	8	2.88	18.10	41.37	
	9	86.20	11.70	53.07	Moderated weathered phyllite
	10	1394.00			Fresh phyllite

Table A.6-9. 1st lateritic topsoil layer consisting of clayey sand and gravel which is 0.74 meters thick, 2nd moderated weathered phyllite layer is 4.14 meters thick, 3rd high weathered phyllite layer is 34.50 meters thick, 4th moderated weathered phyllite layer is 35.60 meters thick, and 5th fresh phyllite layer.

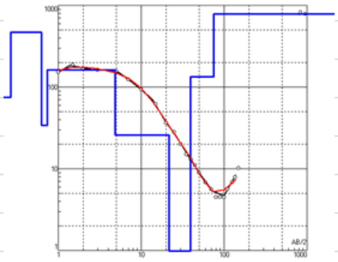
Apparent resistivity curve VES6-11	ID	ρ (Ωm)	Thickness (m.)	bottom depth (m.)	Description
	1	75.00	0.27	0.27	Topsoil
	2	470.00	0.36	0.62	
	3	33.80	0.11	0.74	
	4	162.00	4.14	4.88	Moderated weathered phyllite
	5	25.90	16.90	21.78	High wethered phyllite
	6	0.98	17.60	39.38	
	7	133.00	35.60	74.98	Moderated weathered phyllite
	8	783.00			Fresh phyllite

Table A.6-10. 1st lateritic topsoil layer consisting of clayey sand and underlying laterite which is 2.08 meters thick, 2nd moderated weathered phyllite layer is 1.06 meters thick, 3rd high weathered phyllite layer is 4.40 meters thick, 4th moderated weathered phyllite layer is 6.99 meters thick, 5th high weathered phyllite layer 17.30 meters thick, 6th moderated weathered phyllite layer is 6.48 meters thick, and 7th fresh phyllite layer.

VITA

Mr.Neti Kuaneiam was born on January 26, 1985 in Bangkok. He got Bachalor Degree in Geology from Department of Geology, Faculty of Science, Chulalongkorn University in 2009. He apprenticed as student trainee in Chevron Thailand Exploration and Production Ltd., in 2006 and 2007. During his study, he was representative speaker of Chevron camp 2th in 2007 and got Chevron Scholarship in 2006 and 2007. Then he worked as geologist at GMT corporation co., ltd. for many years. During his work, he attended a training in GEUS, Aarhus University & SkyTEM in Denmark about transient electromagnetic and direct current electrical geophysics method in 2011. He carried out further study on master program in Geology at Department of Geology, Faculty of Science, Chulalongkorn University. During his study, he got education funding scholarship Master Degree in 2011 and he was representative speaker about “Airborne Time-Domain Electromagnetic Survey” in 2012.