Chapter 2
Types of the Geophysical Survey Data

2.1 General background

2.1.1 Geophysical surveys for mineral exploration

Geophysical methods have been increasingly applied in prospecting for mineral deposits, in addition to geological and geochemical methods. Geophysical methods are based on the study of physical fields, which are influenced by the distribution of the rocks characterized by physical properties. These properties are density, magnetism, electrical conductivity and radioactivity. In most cases the target is distinguished by one or more types of anomalous properties. However, the experiences obtained during the search for mineral deposits in Thailand show that it is also possible to use geophysical methods even though the objects searched for are not manifested in physical fields. For example, gold bearing quartz zone that is a resistive zone, could be identified by electromagnetic survey, a tool generally used for conductive body (Prasittikarnkul and others, 1993).

In applied geophysics, the final aim is a concrete geological result. Therefore, the applicability of geophysics is controlled by the level of geological knowledge of the problem under consideration, and the correlation between geophysical and geological investigations. The greater the knowledge of geological conditions of the interesting area the greater the choice of rational set of geophysical methods could be applied. There are few instances of geophysics independently solving simple geological problems. These geophysical applications may be carried out on a regional scale by an airborne survey, or detailed scale by ground surveys, and even during production by bore-hole and mining geophysics.

2.1.2 Airborne geophysical survey in Thailand

Airborne geophysical survey was first introduced in Thailand for petroleum exploration in 1954, but it was limited to the lower part of Chao Phraya basin in the central part of the country. Five years later, three selected targets in Loei, Nakhon Sawan and Chachoengsao were surveyed with a combined airborne magnetometer and scintillometer. The result was published in USGS Professional Paper number 618 (Brown and others, 1951). In 1969, two private companies conducted aeromagnetic surveys for petroleum exploration in the upper Chao Phraya basin and Khon Kaen areas. Many drilling targets were consequently located and the petroleum exploration era in Thailand began ever since.

Later in 1979, Sander Geophysics, a Canadian company conducted combined airborne magnetic and radiometric surveys covering the eastern, and airborne radiometric survey covering Phu Wiang basin in the northeastern parts of the country. These surveys were acquired for mineral exploration, metallic ore and radioactive ore respectively. Surinkum (1989) used the aeromagnetic data made by Sander Geophysics over eastern Thailand to outline paleo-boundary zone and concealed structures. Three areas of interest were recommended for further ground check and one of them was investigated in a detailed scale for porphyry copper (Leungingkasoot and Yawichai, 2000).

Since 1985, the oil companies operated in the country conducted their own airborne and marine geophysical data acquisition in the Gulf of Thailand for petroleum explorations. Unfortunately these data in detailed scale are not accessible to academic or the public. However, a regional scale data can be obtained from United Nations-funded organizations and only regional structure can be outlined (Geological Survey of Japan, 1994).

The data used in this study are part of the airborne geophysical survey data acquired during 1984-1988 by Kenting Earth Science International Limited (KESIL) of Canada with the contract from the Department of Mineral Resources (DMR) through the Mineral Resources Development Project (MRDP). These surveys for high-resolution magnetic and high sensibility radiometric cover the whole nation. In addition, helicopter-borne electromagnetic surveys were conducted over five selected areas. The Nan-Uttaradit suture zone is one of the selected areas, although only the area around Sirikit dam was of interest for a helicopter-borne electromagnetic application (KESIL, 1989). These data are available in both digital and analog format for public use, at a price. Normally, the data is set concordance with the topographic map indexing as a general map sheet or a grid reference (Hatch and others, 1994). For example, a whole set of airborne geophysical data covers a 1:50,000 scale map sheet costs not more than 5,000 Baht for a digital format and 100 Baht for a single data type on a hard copy.

Private companies, aiming at more specific mineral types such as gold and petroleum, conducted subsequent airborne geophysical surveys. Table 2.1 summarizes all of the airborne geophysical activities in Thailand.

Table 2.1 Airborne geophysical surveys in Thailand

Date Flown	Area	Methods	Organizer	Purpose
1954	Lower Chao Phraya Basin	Magnetic	DMR	Petroleum exploration
1959	Loei	Magnetic& Radiometric	DMR by USAID fund	Mineral investigation
1959	Chachoengsao	Magnetic & Radiometric	DMR by USAID fund	Mineral investigation
1959	Nakhon Sawan	Magnetic & Radiometric	DMR by USAID fund	Mineral investigation
1963	Kanchanaburi	Magnetic	Private	Mineral investigation
1965	Loei (east)	Magnetic	Private	Mineral investigation
1979	Khon Kaen	Magnetic	Private	Petroleum exploration
1979	Upper Chao Phraya Basin	Magnetic	Private	Petroleum exploration
1979	Phu Wiang	Radiometric	DMR	Uranium exploration
1979	Eastern Thailand	Magnetic & Radiometric	DMR	Mineral investigation
1984	Nationwide	Magnetic, Radiometric, VLF-EM& AEM	DMR	Regional mapping & Mineral investigation
1985-1997	Gulf of Thailand	Magnetic	Private	Petroleum exploration
1997	Loei & Petchabun	Magnetic	Private	Gold exploration

2.1.3 Ground follow-up surveys over airborne anomalous zone

In practice, there are three objectives of ground follow-up surveys, to evaluate an anomaly to probable cause, to measure the parameter of the causative body, and to locate the source accurately on the ground (Beck, 1981). In general, ground geophysical surveys are used to verify types of anomalies while both geological and geochemical surveys are used to discriminate between ores and others with similar physical property. The ground geophysical follow-up surveys, including magnetic, electromagnetic, resistivity and induced polarization, were done in various areas. A total of eight different geophysical techniques were applied based on their advantages and disadvantages, especially for mineral explorations. The result of each technique will be used as a guideline for further mineral exploration not only in this study area but also in the areas with similar conditions.

2.2 Airborne geophysical data of the study area

2.2.1 Aeromagnetic data

The aeromagnetic survey, Survey A, was flown by fixed wing aircraft in blocks at various altitudes ranging from 1,000 ft or 330 m MTC (mean terrain clearance) to 7,500 ft or 2,500 m fixed barometric altitude depending on the relief of the terrain (Figure 2.1). The flight lines are in north-south direction with 1,000 m spacing and 14,000 m control line spacing. The data were collected by a cesium magnetometer with 0.01nT (nano-Tesla) resolution. Figure 2.2 shows the aeromagnetic data of the study area.

2.2.2 Airborne radiometric data

The radiometric surveys, Survey B and Survey C, were flown at 120 m or 400 ft MTC, with 1, 2 and 5 km line spacing in east-west direction (Figure 2.3). Survey B and Survey C are different by the types of the aircraft used in the surveys. Survey B was flown by a twin-engine fixed wing aircraft over low relief terrain while Survey C was a helicopter flown over rugged terrain mostly in the west of the country. The data were acquired by gamma ray spectrometer with four data recording windows covering all energy windows. These windows are total count window (Figure 2.4), potassium window (Figure 2.5), uranium window (Figure 2.6) and thorium window (Figure 2.7), for 0.40-2.82 Mev, 1.36-1.56 Mev, 1.66-1.86 Mev and 2.42-2.82 Mev respectively. Ternary map, a superimposed map of potassium, uranium, and thorium elements with different colours assigned, can be used to study theirs correlation (Figure 2.8).

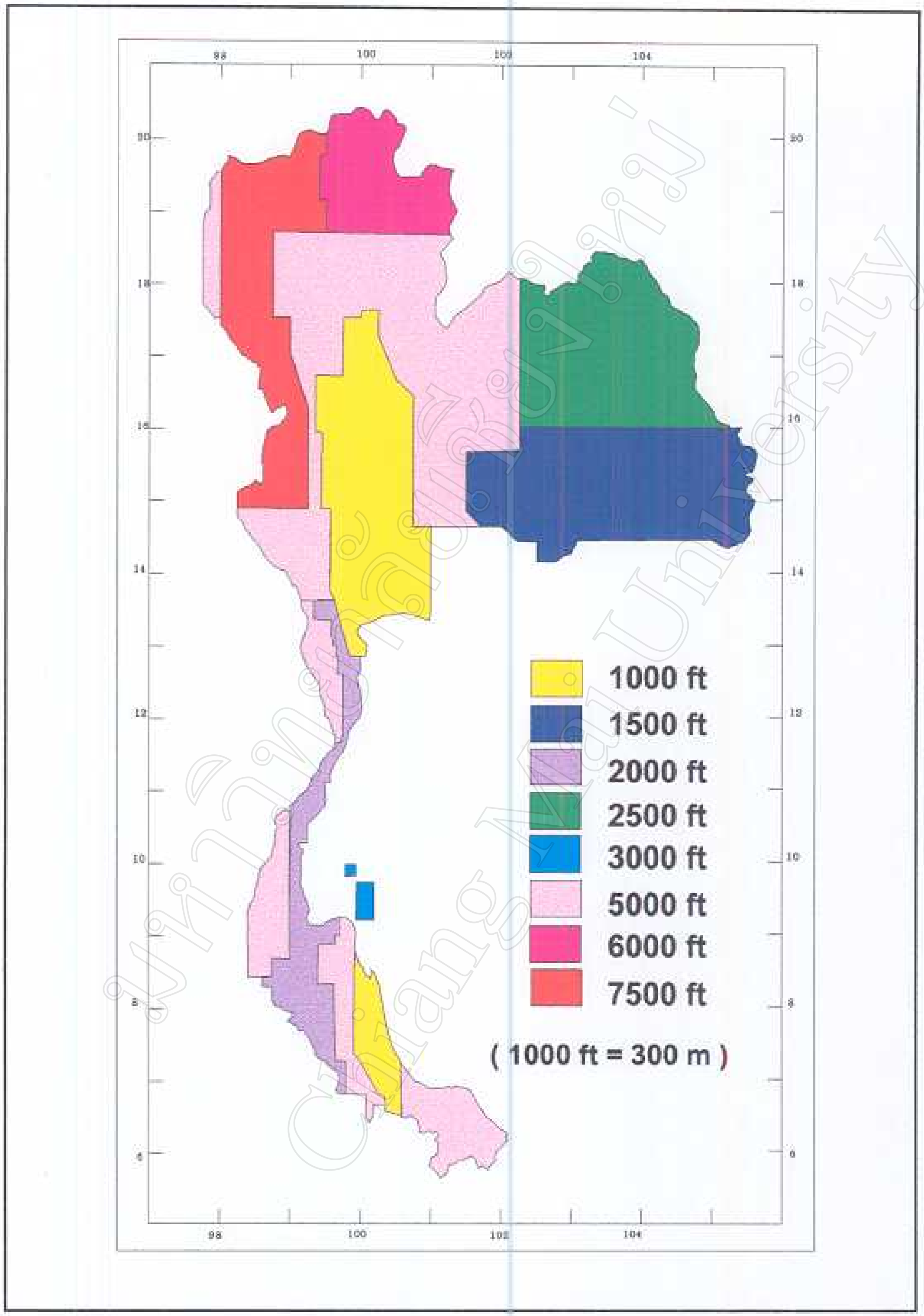


Figure 2.1 Area flown by airborne survey A with specified flight altitude. (after Sukontapongpow , 1997)

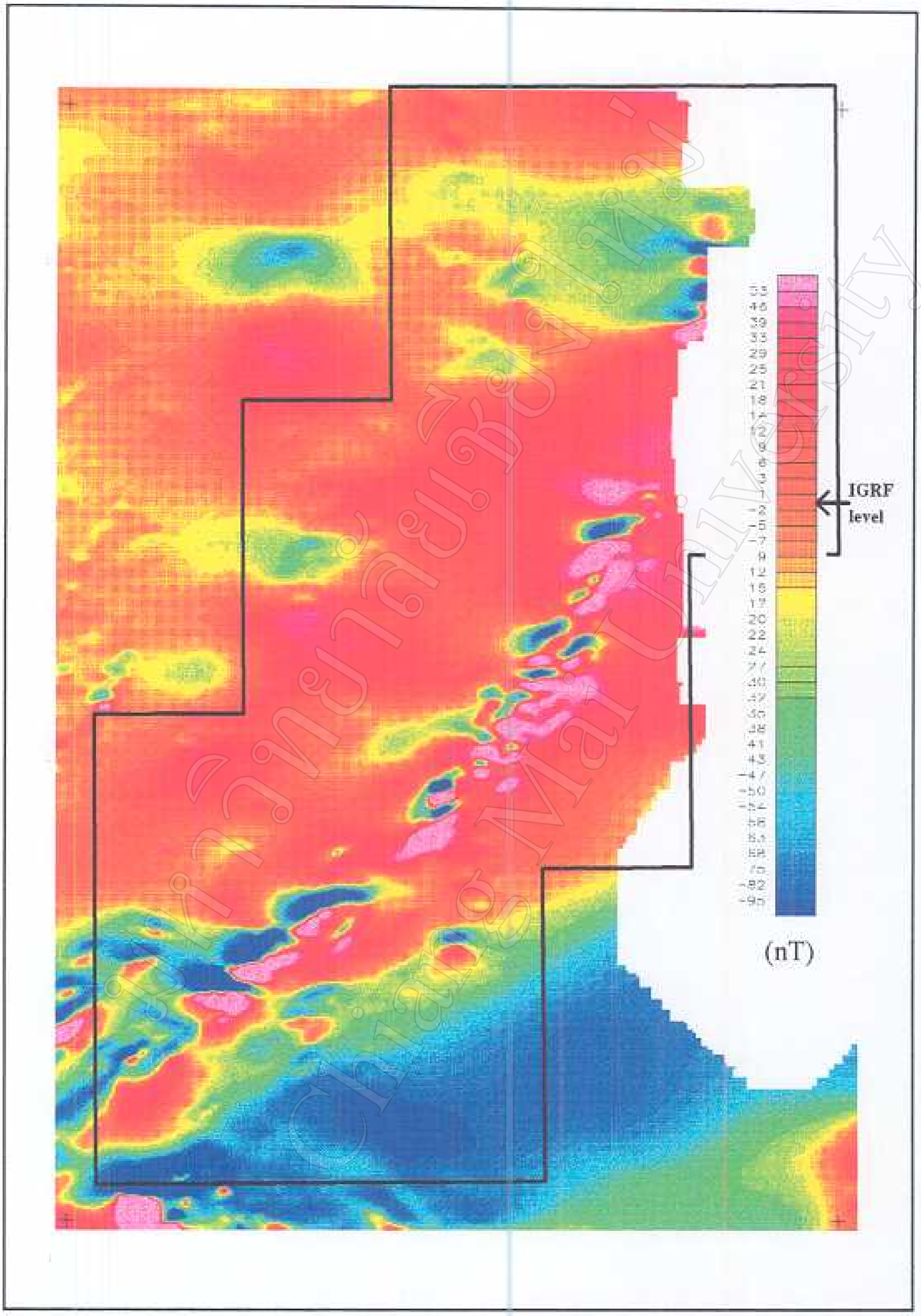


Figure 2.2 Aeromagnetic data (residual field) of the study area.

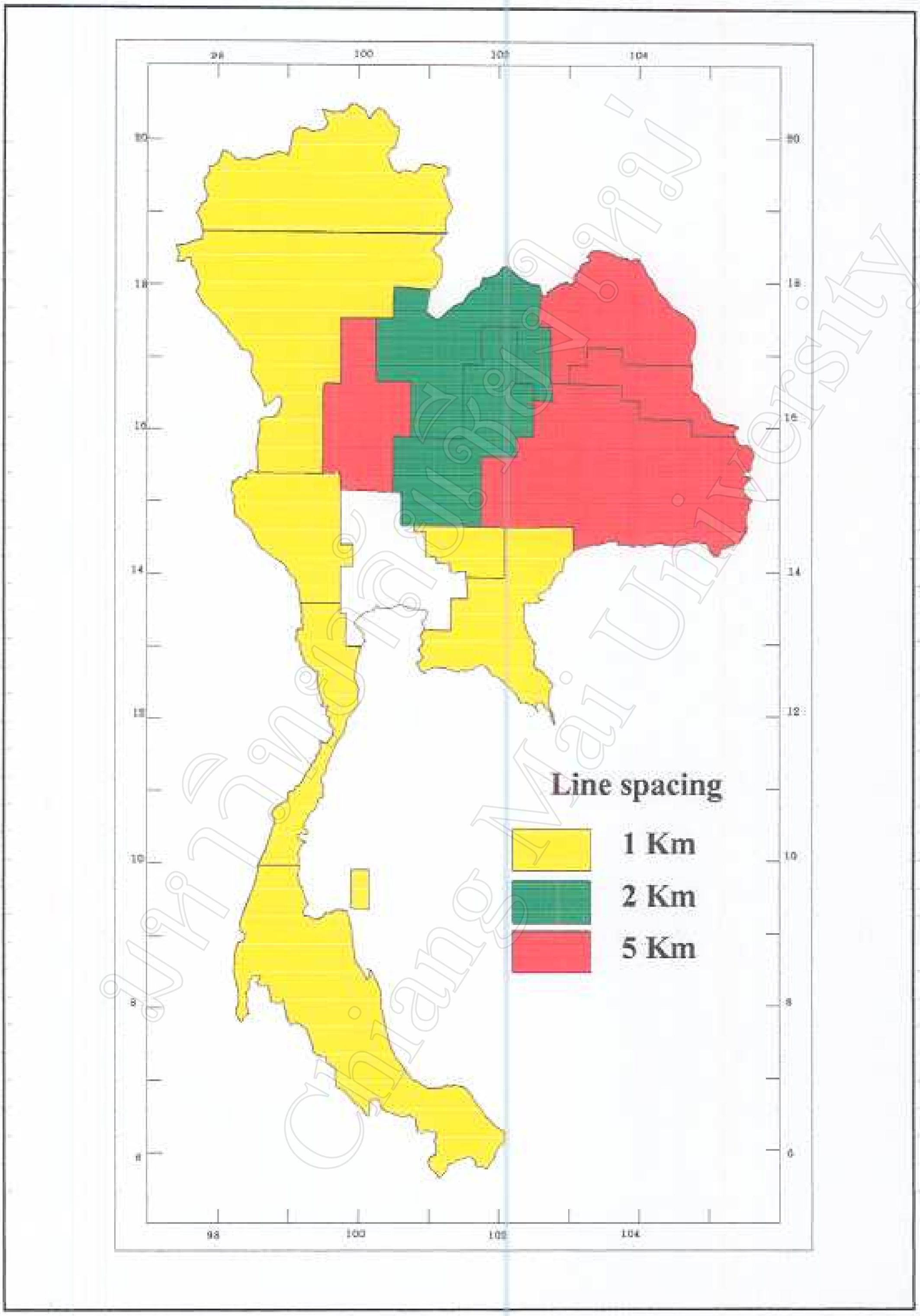


Figure 2.3 Area flown by airborne survey B and C with specified traverse line spacing.
(after Sukontapongpow , 1997)

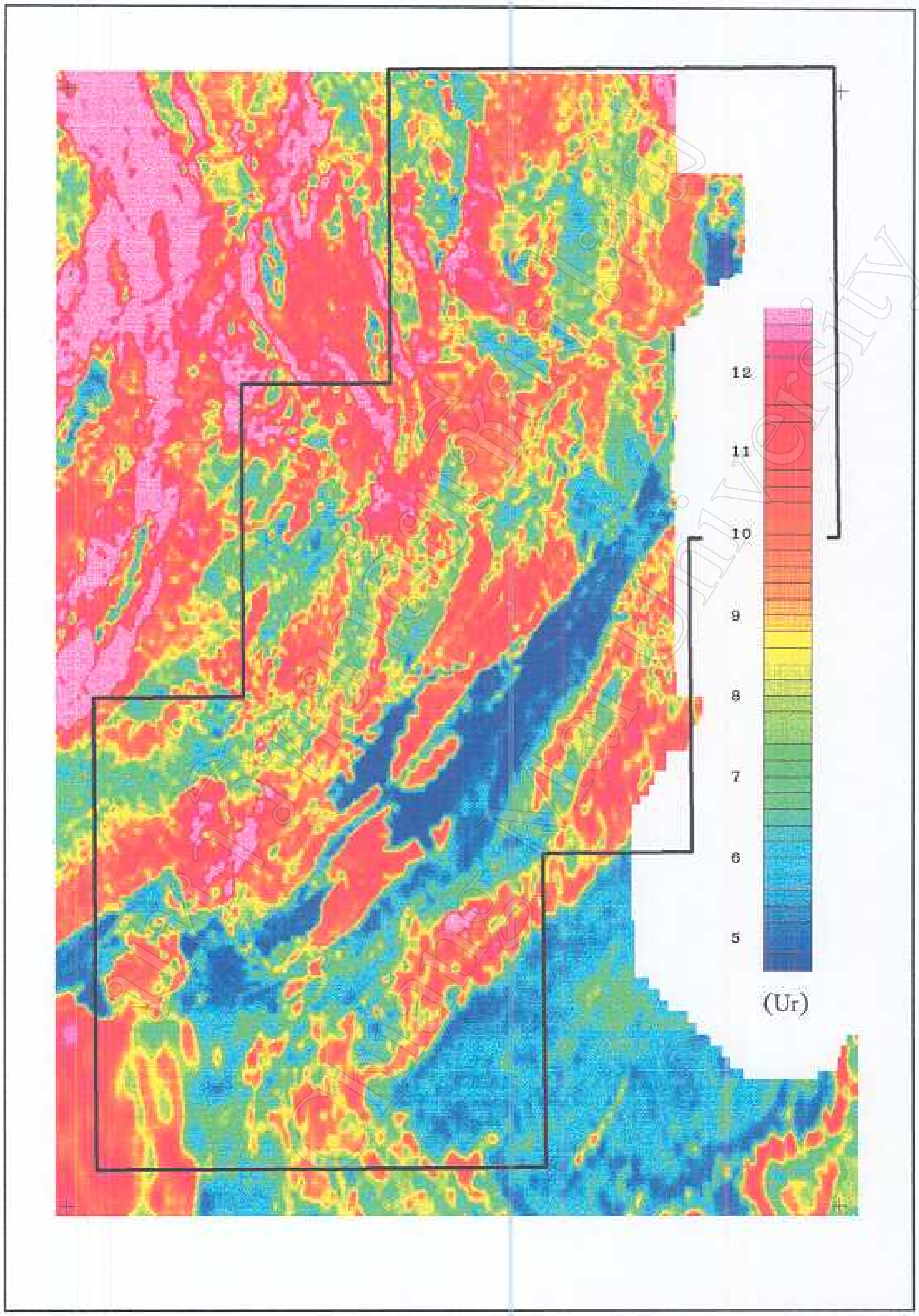


Figure 2.4 Airborne radiometric (total count) data of the study area.

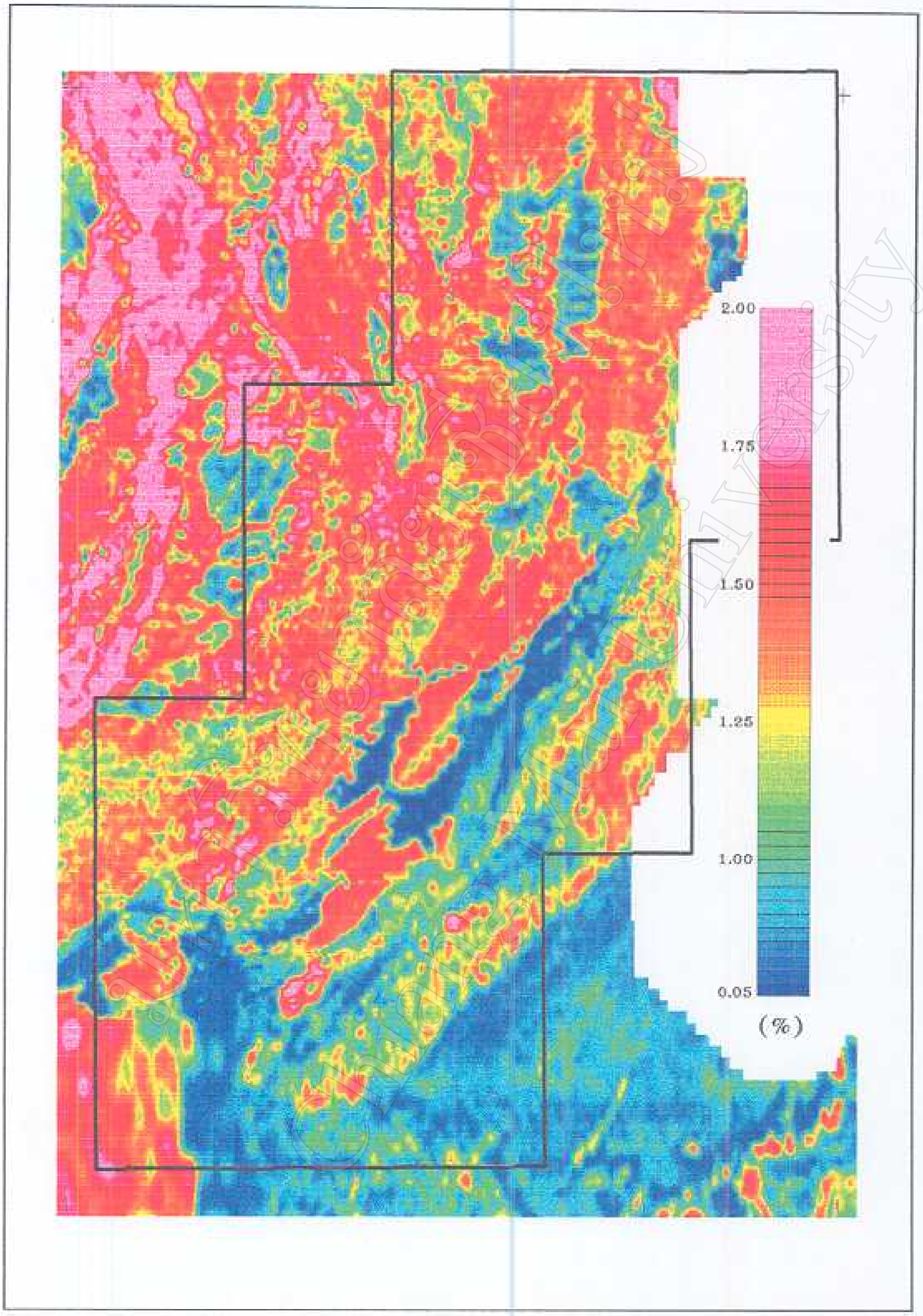


Figure 2.5 Airborne radiometric (potassium) data of the study area.

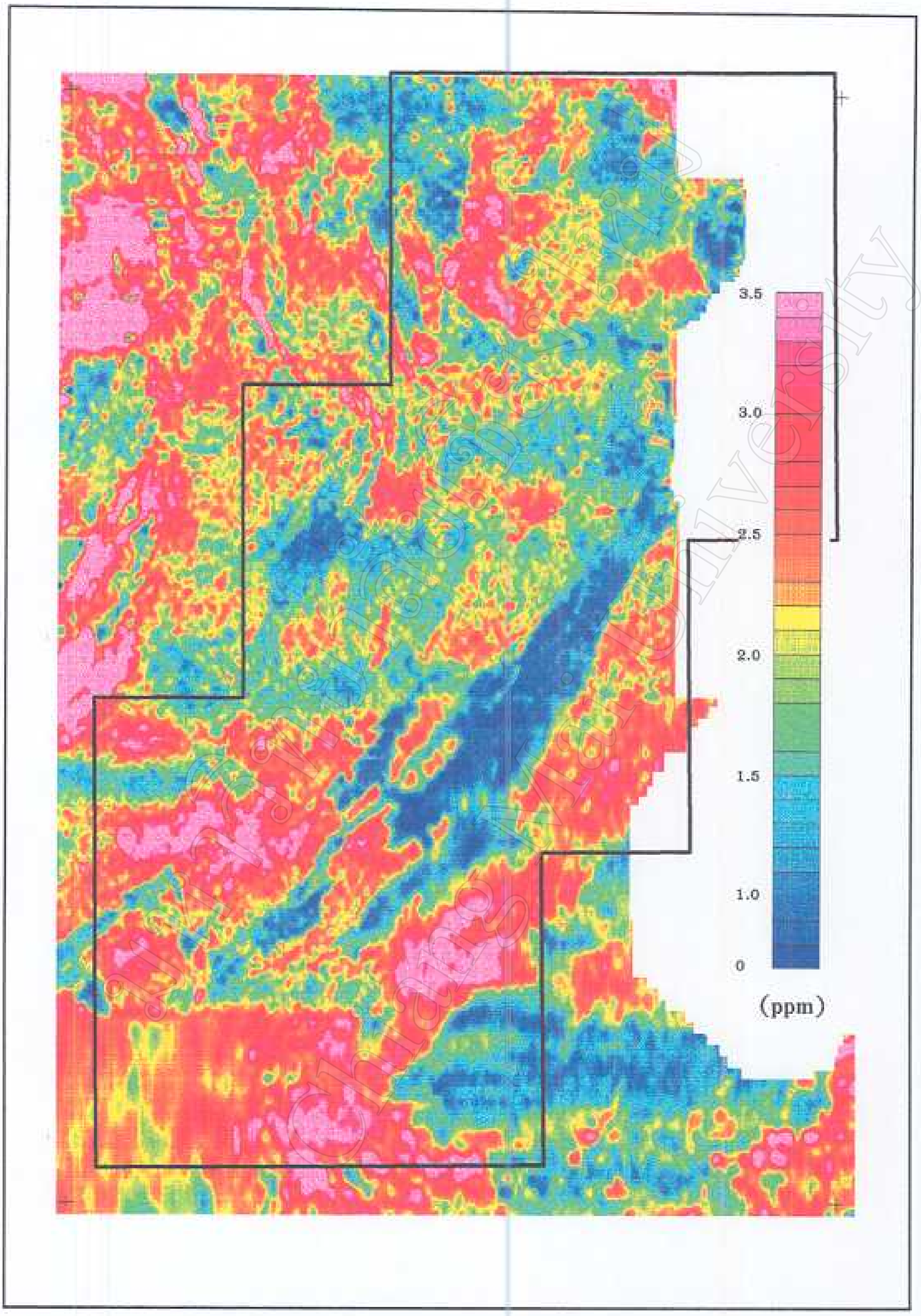


Figure 2.6 Airborne radiometric (uranium) data of the study area.

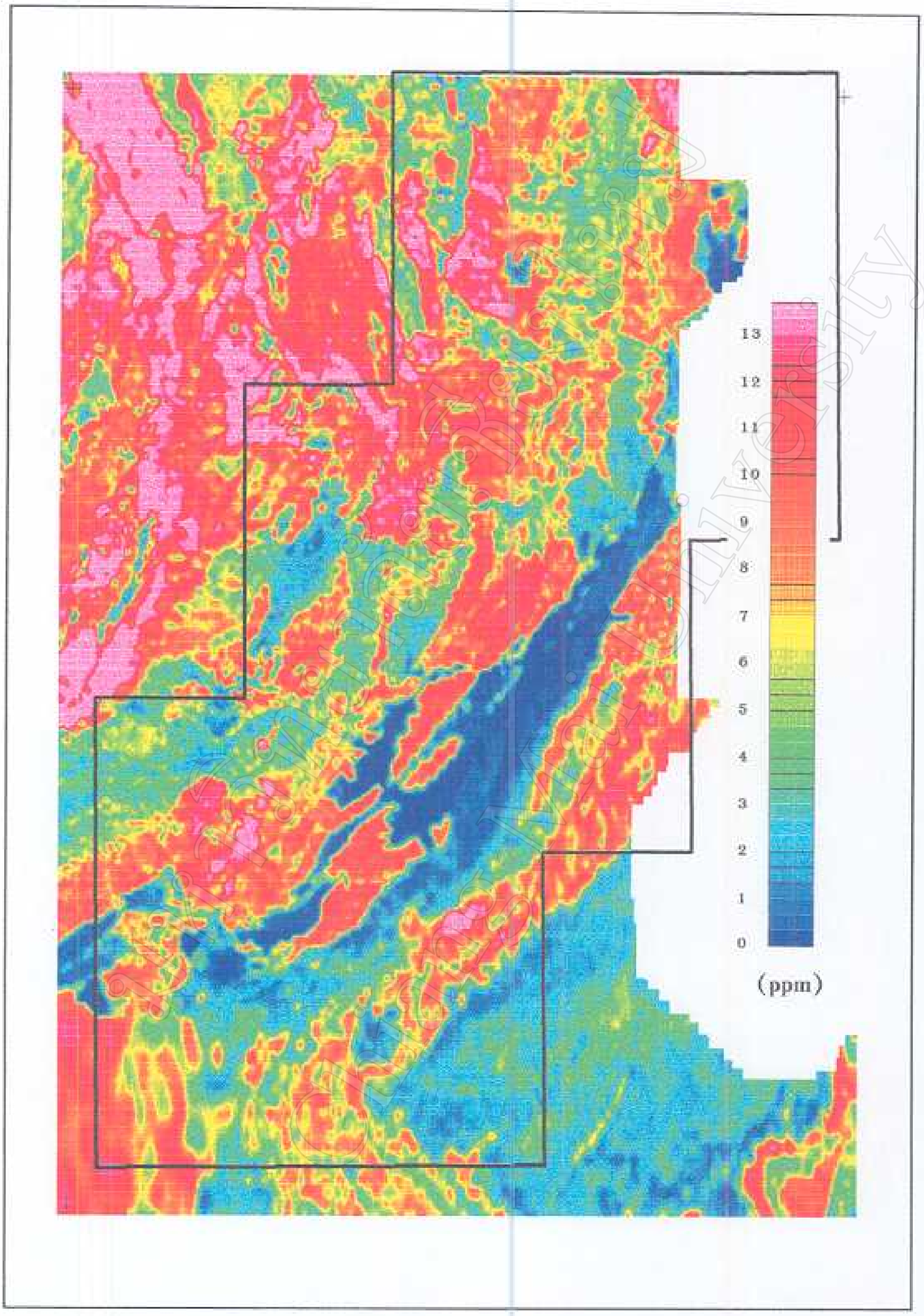


Figure 2.7 Airborne radiometric (thorium) data of the study area.

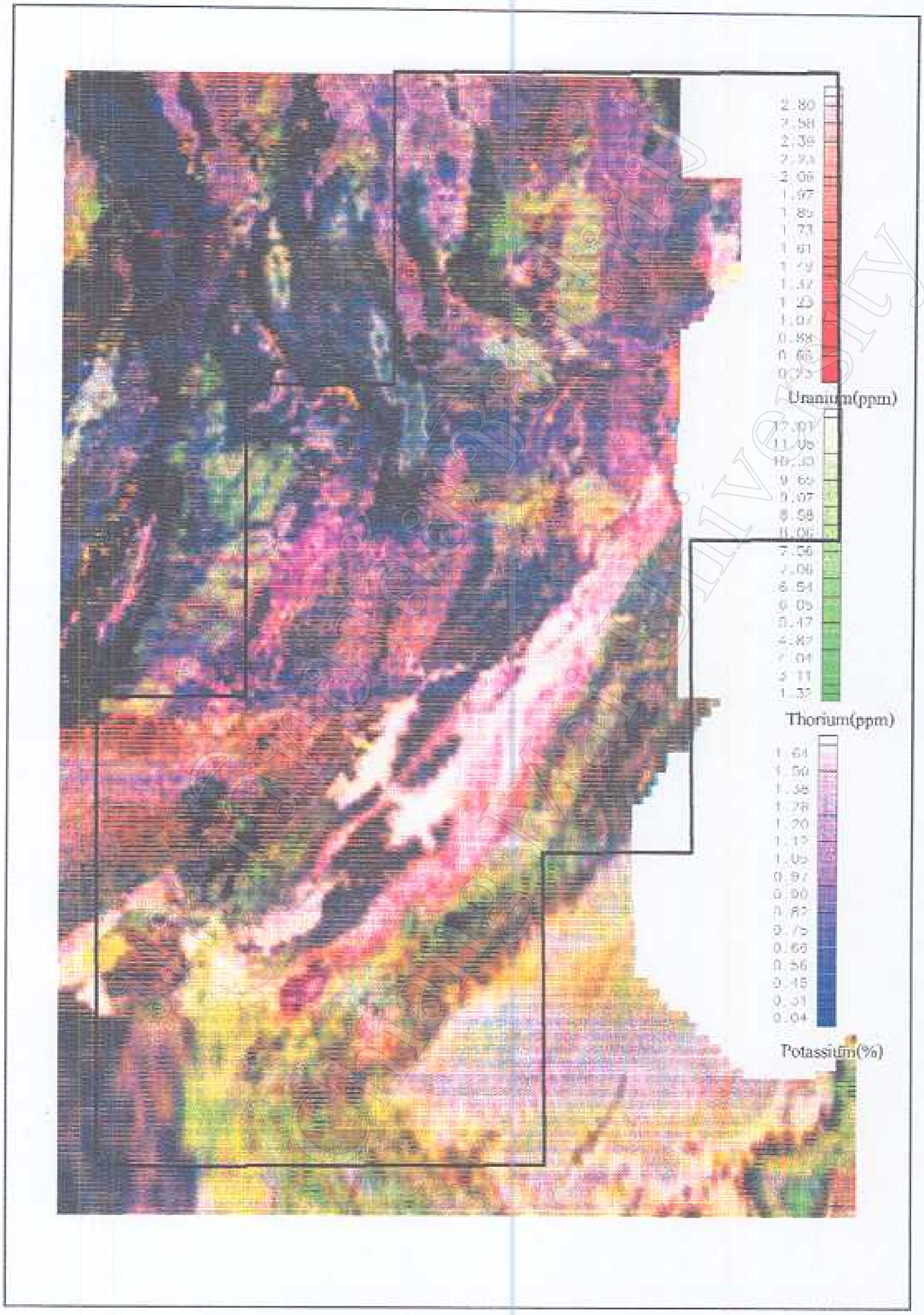


Figure 2.8 Airborne radiometric (ternary) data of the study area.

2.2.3 Airborne VLF electromagnetic data

VLF electromagnetic (VLF-EM) system has been developed to take advantage of high power communication transmissions used in a military purpose in the 15-25 kHz band. The VLF (very low frequency) term is used because this is very low in terms of the communication frequencies. The surveyed area is usually far from the transmitting stations so that the primary field is uniform in the resistive area. This makes theoretical prediction of anomalies relatively simple.

VLF-EM sensors were set to match with the stations both in Australia (NWC station of 22.3 kHz) and Japan (NDT station of 17.4 kHz). The data were stored in a profile format and a grid file including both total field and quadrature components, where stacked profiles and intensity contour can be overlaid on both 1:50,000 and 1:250,000 topographic maps. The magnetometer and VLF-EM sensors were also equipped with an airborne spectrometer.

2.2.4 Helicopter-borne electromagnetic data

This is a follow-up survey acquired by a helicopter borne system, a combination of electromagnetic and magnetic systems. Five mineral potential areas were selected for this survey type: Loei, Lampang-Phrae, Uttaradit-Nan, Phetchabun and Kabin Buri (Figure 2.9). A normal 400 m line spacing and 30 m survey altitude was used and flight direction depended on geological structure in each area. The acquisition was done during 1987-1988. The HEM data used in this study is a stacked profile (Figure 2.10) that can be examined and classified according to conductance (Figure 2.11).

2.3 Ground geophysical data of the study area

2.3.1 General procedure

Ground geophysical data are normally gathered along straight lines pegged at regular intervals, but readings may also be made at points distributed more or less randomly over the survey area. Even with random coverage readings, natural-field measurements can be made for each distinct body, since the detection made from ground geophysical surveys are always placed some distance from the artificial sources or cultures.

2.3.1.1 Data presentation

If geophysical data are collected along traverse lines, the result can be presented in a profile form. The horizontal scale is always of a distance while the vertical scale is of the quantity being measured. In general, it is possible to plot a profile in the field as work progresses. Such plots are vital for quality control of field works. Traverse lines drawn on the topographic map can be used as

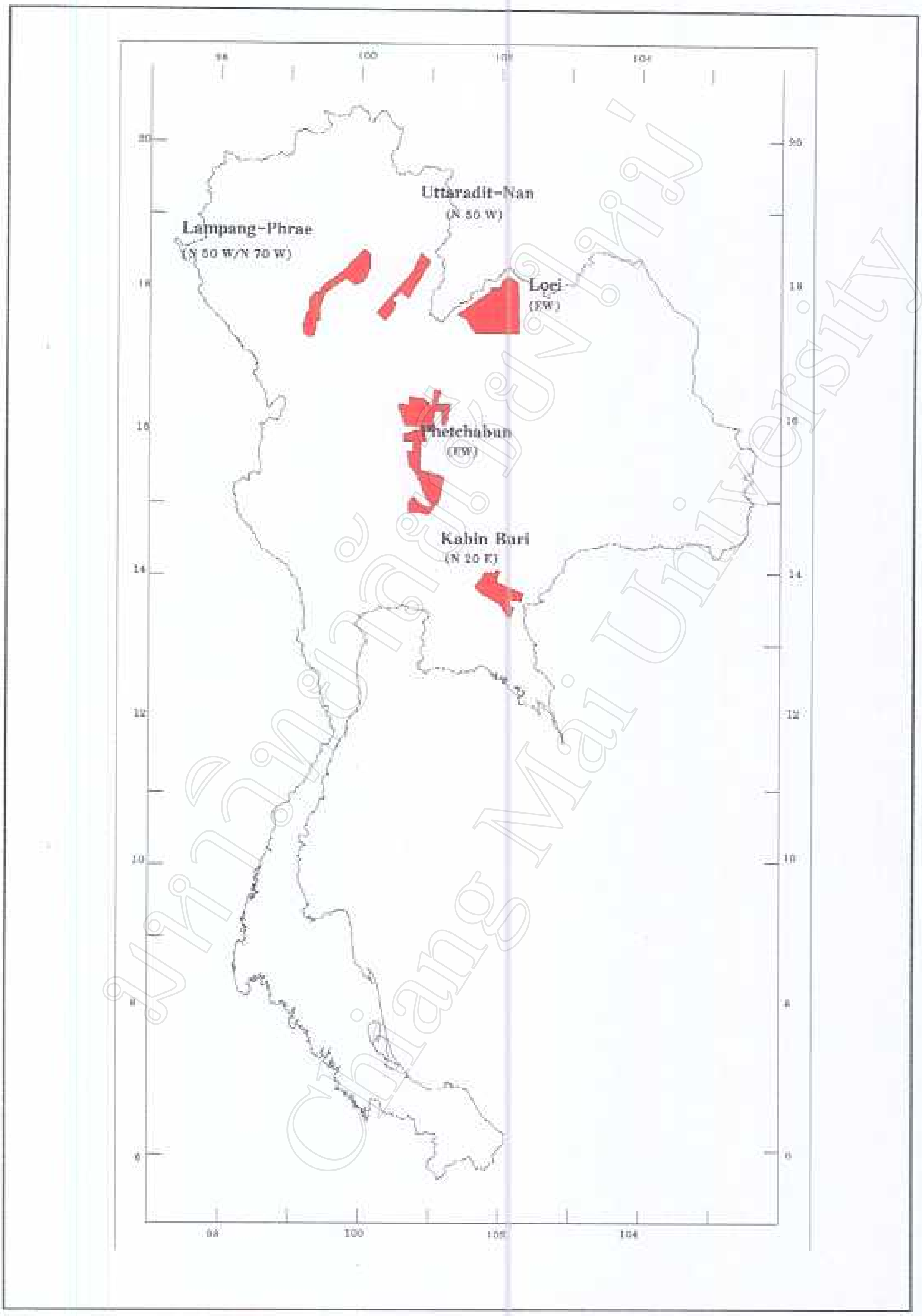


Figure 2.9 Five potential areas flown by helicopter-borne electromagnetic with specified traverse line direction.
(after Sukontaponpow , 1997)

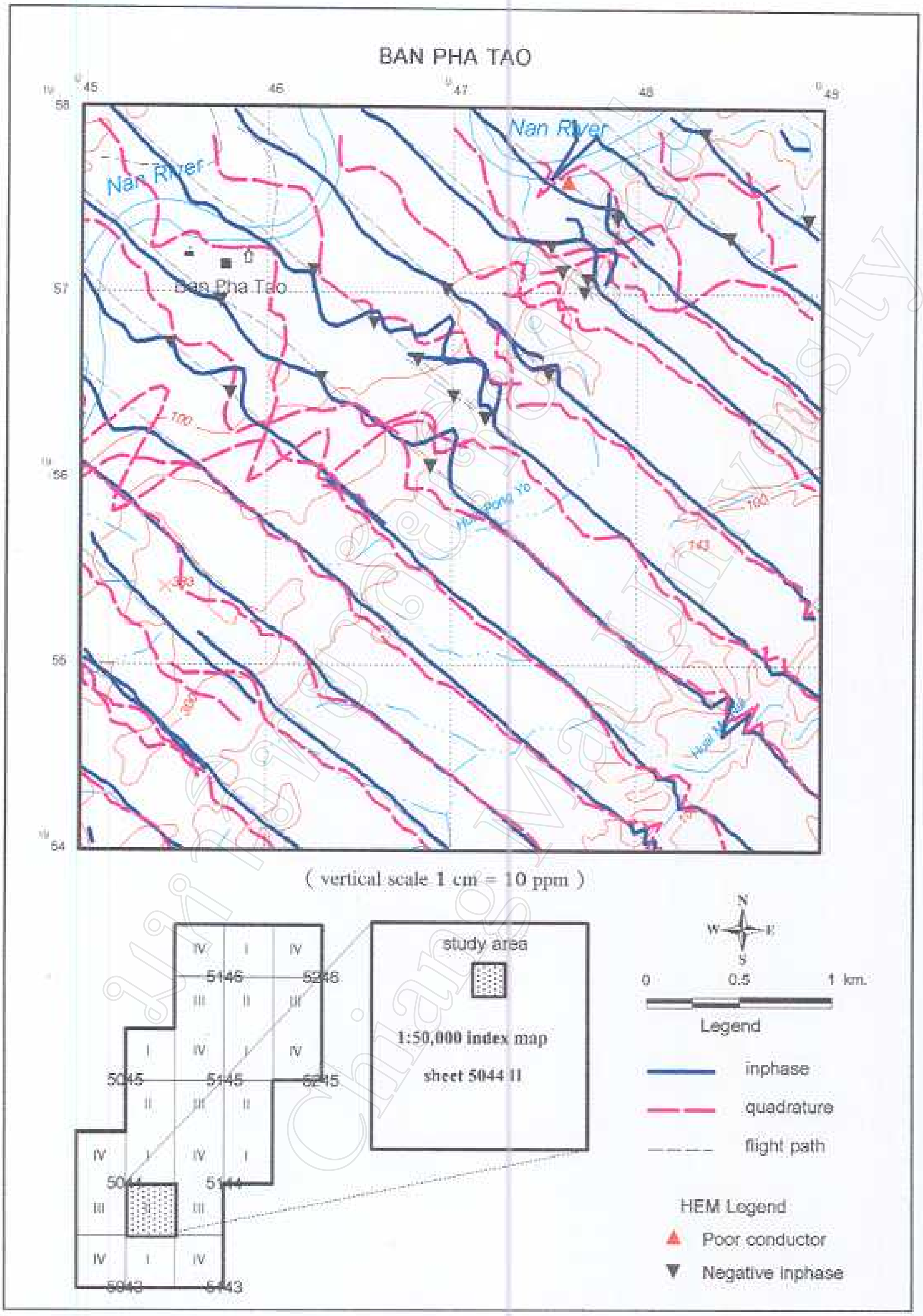


Figure 2.10 Selected stacked profile of a helicopter-borne electromagnetic data of the study area.

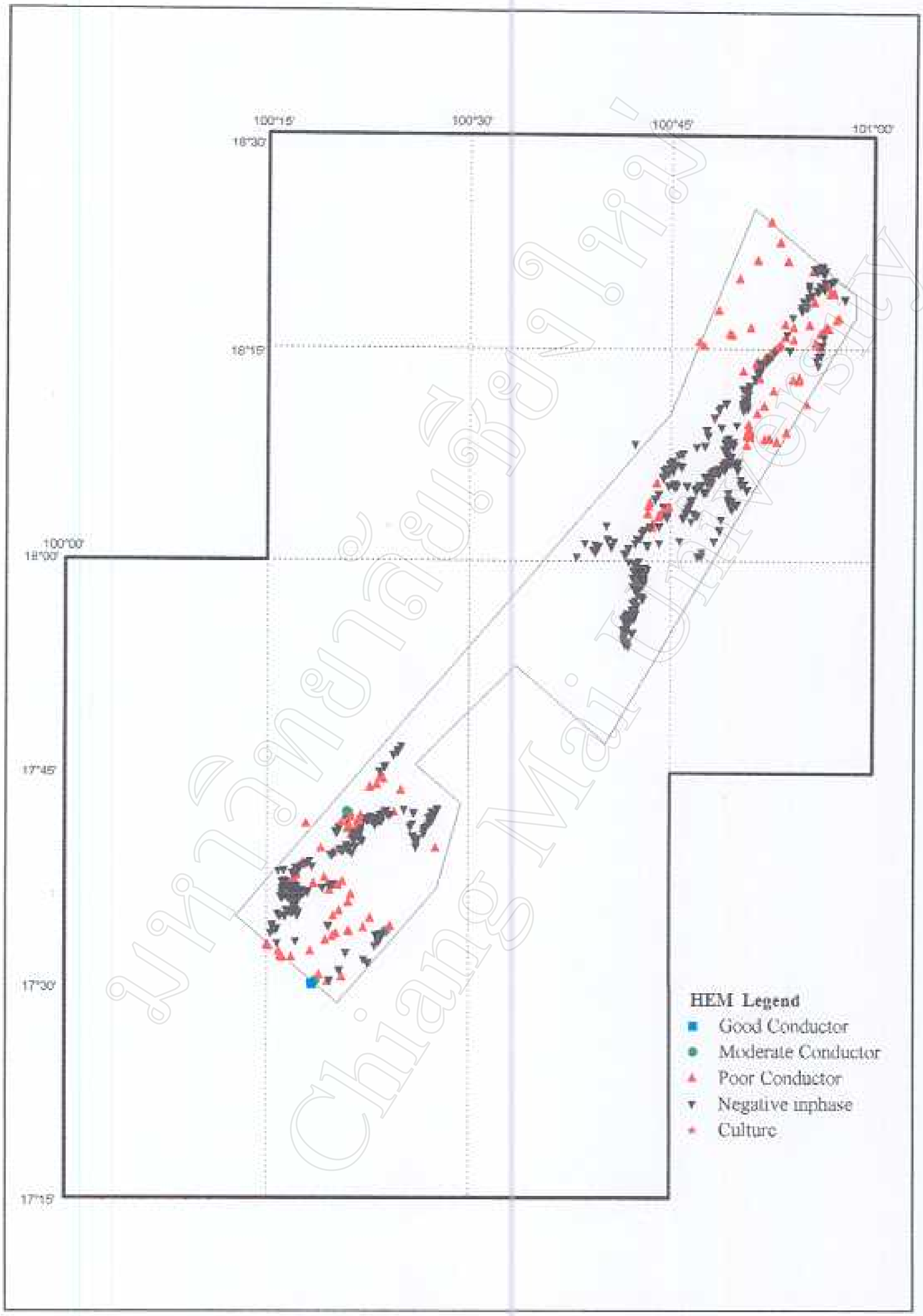


Figure 2.11 Map showing classified HEM anomalies using conductance and inphase characters. (after KESIL , 1989)

baselines for profile plots. The presentations are particularly helpful for identifying anomalies due to man made features, since correlation with roads and field boundaries are obvious. The multiple profile or stacked profile is often used to outline the anomalous trend.

Contour map is drawn in the field if the strike of some features must be defined so that the in-fill work can be planned. Some information may be lost in contouring because it is not generally possible to choose a contour interval that faithfully records all features of the original data. Cross-section or pseudo-section is another type of presentation. This is the most popular for electrical dipole-dipole array where traverse and depth of determination can be outlined easily.

2.3.1.2 Geophysical anomaly

Unlike geological or geochemical information, only rarely is a single geophysical observation significant. Many readings are needed and a background level must be determined before any interpretation can begin. Interpreters tend to concentrate on anomalies, where there are differences from a constant or smoothly varying background.

Separation of observations into patterns of regional and residuals is an important part of geophysical data processing. Furthermore, it may be necessary, in the field, to estimate background so that the significance of local anomalies can be assessed. The existence of an anomaly indicates the difference between the real world and some idealized model. Normally specific terms are used to denote the derived quantity, which records the difference from simple earth models. Anomalies must be explained in terms of geologic conditions, including the possible occurrence of ore mineralization.

There are generally a few alternative conditions that could cause similar anomalies. An example from Canada, one airborne electromagnetic anomaly in ten is designed as "probable significant", and one in ten of these proves to be associated with sulphide bodies, and one in fifty of the sulphide bodies is classified as potential ore body. The ratio is one potential ore body to 5,000 airborne electromagnetic anomalies in the world most promising area for massive sulphide mineralization (Peters, 1987).

2.3.1.3 Working sequence

Normally, a geophysicist chooses field methods and traverse on the basis of interpreted geology, and a geologist uses geophysical information in making a geological model. Therefore, few sequences must be assigned:

1. consideration of a conceptual model, where all related geological units are summarized in a simple model,

2. preparation for geophysical work based on the conceptual model,

3. coordination work between field geologists and field geophysicists so both principles can be integrated, and

4. follow-up work using other geophysical methods if the complex geological model must be outlined.

2.3.2 Magnetic survey

Magnetic method detects rocks or mineral concentration possessing anomalous magnetic properties. The methods measure static magnetic field at or above the earth surface, and relate these measurements to the direct resolution of discrete magnetic bodies. The magnetic intensity is used to explain type of magnetic substance as well as environment descriptions of lithologic and structural variations within the earth.

Rock magnetism is a function of magnetic susceptibility, the ease with which the constituent minerals may be magnetized. There are only two mineral groups that can be magnetized. The iron-titanium-oxygen group possesses a solid solution series of magnetic mineral from magnetite (Fe_3O_4) to ulvospinel (Fe_2TiO_4). However, common iron oxide, hematite (Fe_2O_3) is antiferro-magnetic and therefore does not give rise to magnetic anomalies. The other group is pyrrhotite, an iron-sulphur mineral, provides the magnetic mineral whose magnetic susceptibility is dependent upon the actual composition. The size, shape and dispersion of the magnetic grains within a rock also affect its magnetic character (Kearey and Brooks, 1984).

A magnetic body, buried in the ground, is subjected to the Earth's magnetic field. The magnetic moments of the ferro-magnetic material contained such a body aligned along this field. These element dipoles produce an induced polarization vector in the same direction, which in turn produces the dipole field. A magnetometer, at or above the Earth's surface, measures the total magnetic field that is a vector sum of the geomagnetic field and the induced field.

An early magnetometer, torsion balanced, uses needles mounted on horizontal axes to measure vertical field. This type was commonly used until 1960s, when it was replaced by fluxgate and proton precession magnetometers (PPM). The latter one is now being used extensively to measure the total magnetic intensity and a simple calculation can be made afterward to get both vertical and horizontal magnetic field.

Ground magnetic survey data used in this study was obtained during 1994-1998 by the author and his colleagues through the Mineral Resources Development Project (MRDP). Two proton precession magnetometers, PPM G-856 of Geometrics, were used as both the base station and the measurement gear (Figure 2.12). The system makes use of the small magnetic moment of the hydrogen nucleus (proton) that precession frequency is proportional to the external magnetic field. It can store the data that can be recalled to the front panel display

Figure 2.12 The proton magnetometer.

or for transfer directly to printer or computer. Each stored reading has a serial number and recording times. Therefore, an automatic reading at the base station can be used to monitor diurnal variations. The diurnal corrected data must be subtracted from the International Geomagnetic Reference Field (IGRF) to get a residual field for any further manipulations (Merrill and McElhinny, 1983).

2.3.3 Horizontal loop electromagnetic survey

In the horizontal loop electromagnetic (HLEM) survey, receiver and transmitter coils are kept coplanar at a fixed separation for a maximum coupling. When surveying, both coils, coupled by reference cable, move as a unit along the traverse line. Their readings are normally taken at the intervals equal to one-fifth of the coil separation. Over the neutral ground no secondary field is presented, both inphase and quadrature components can be zeroed. Over and vicinity of the conductor, readings are subsequently obtained and therefore provide a measure of inphase and quadrature components of the secondary field. These are generally expressed in per cent of the primary field intensity at the receiver.

The field procedure is simple and requires a crew of only two or three operators. The spacing and orientation of the coils are critical as small percentage error in spacing can produce appreciable error in phase measurement. The coil must be kept accurately horizontal and coplanar as small relative tilts can produce substantial errors. The required accuracy of spacing and orientation is difficult to maintain with large spacing and over uneven terrain.

In this study, the ground works were done by MaxMin I system of Apex of Canada (Figure 2.13). The reading was made with 100 and/or 150 m coil spacing, and 8 frequencies (110, 220, 440, 880, 1760, 3520, 7040, and 14080 Hz). Each frequency can be used to study the conductivity contrast at depth depending on its skin depth (Neawsuparp and Paiyarom, 1992).

2.3.4 Very low frequency electromagnetic (VLF-EM) survey

This survey is the far field electromagnetic method using the carrier wave transmitted from the pre-existing stations. Powerful radio transmitters located in different countries transmit unmodulated carrier waves for the purpose of the military communication, the frequencies in the band 15-25 kHz (Figure 2.14). This band is a very low frequency compared to the normal radio frequency. It should be borne in mind that this is not a low frequency signal in the sense of electromagnetic method in applied geophysics. The regular commercial radio frequency is not use because its frequency will give a very low skin depth. In this study, the NWC station of Australia that transmits 22.3 kHz signals with 100 kW power, was used as a primary field source. It was selected because of its strong signal even though its direction not aligns with the general structural strike and the maximum coupling is not expected (Surinkum and others, 1994).

a)

b)

c)

a) MaxMin I HLEM set

b) HLEM receiver panel

c) HLEM horizontal mode

Figure 2.13 The horizontal loop electromagnetic system.

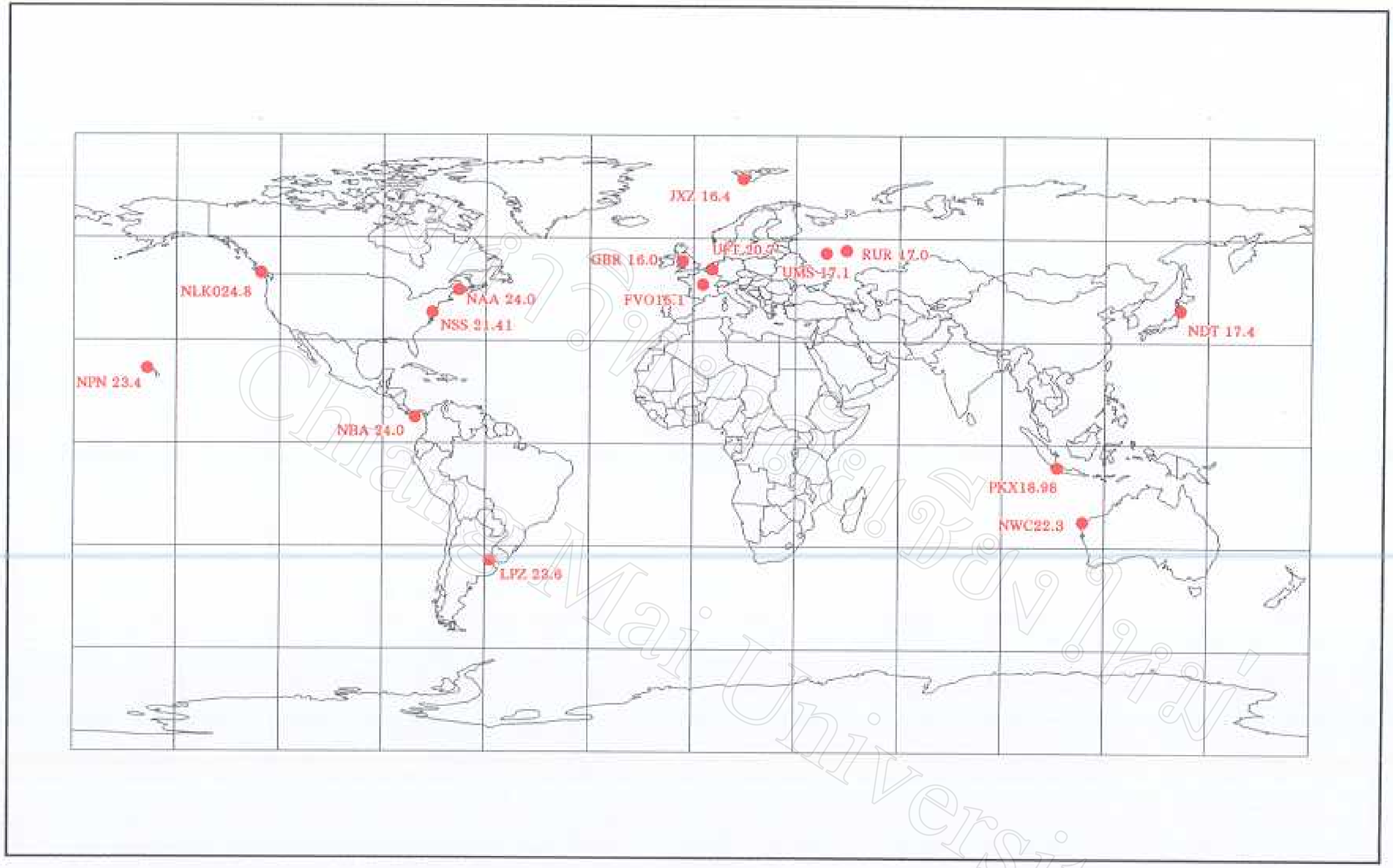


Figure 2.14 VLF stations and their frequencies around the world.

The VLF-EM wave arriving at any point is refracted vertically downwards into the ground irrespectively of its angle of incidence. Above the uniform Earth, when the ground wave of vertical polarized VLF wave meets the conductive body in the ground, eddy current is created causing the secondary fields to radiate outward from its center. Both magnetic and electrical modes can be measured separately by EM-16 of Geonics (Figure 2.15a) or simultaneously by an instrument name VLF-3 of Scintrex (Figure 2.15b) and the field data are stored in the memory part for further study. Magnetic mode will be used for the study of conductivity where the electrical mode for resistivity contrast of the ground surface.

2.3.5 Terrain conductivity measurement

This procedure is usually done by a single frequency domain electromagnetic system. It is designed especially for a terrain conductivity measurement. The first of this is the conventional resistivity survey, which requires a relatively large amount of manpower to execute and is thus expensive. An additional problem inherent to resistivity technique is that although the effective depth of exploration is determined by the selected electrode spacing. However, if resistivity differences are located near the potential electrodes, significant error may occur in the measurement (Utha-aroon and Surinkum, 1995), unless an electrical booster is used for driving more powerful current to the ground.

The secondary magnetic field, measured in the receiving coil, is a complicated function of inter-coil spacing, the operating frequency and the conductivity. Under certain constraints, the conductance is measured from the ratio of primary and secondary magnetic fields. The system used in this study is the terrain conductivity meter named EM-34 of Geonices, Canada (Figure 2.16). Two different configurations were applied, horizontal dipole (Figure 2.17a) and vertical dipole (Figure 2.17b). The apparent conductivity can be measured at 7.5m, 15m, 30m and 60m depths with different configurations and spacing. Therefore, it is also suitable for groundwater exploration where the conventional resistivity survey is difficult to apply.

2.3.6 Time domain electromagnetic survey

Electromagnetic energy can be supplied to the ground by transient pulse, pulse electromagnetic field (PEM), instead of by continuous waves. With a continuous wave application, a small secondary field must be measured in the presence of a much larger primary field. This problem may be overcome by using a primary field, which is not a continuous but consists of a series of pulses and secondary field is measured in between while no primary field is generated. The

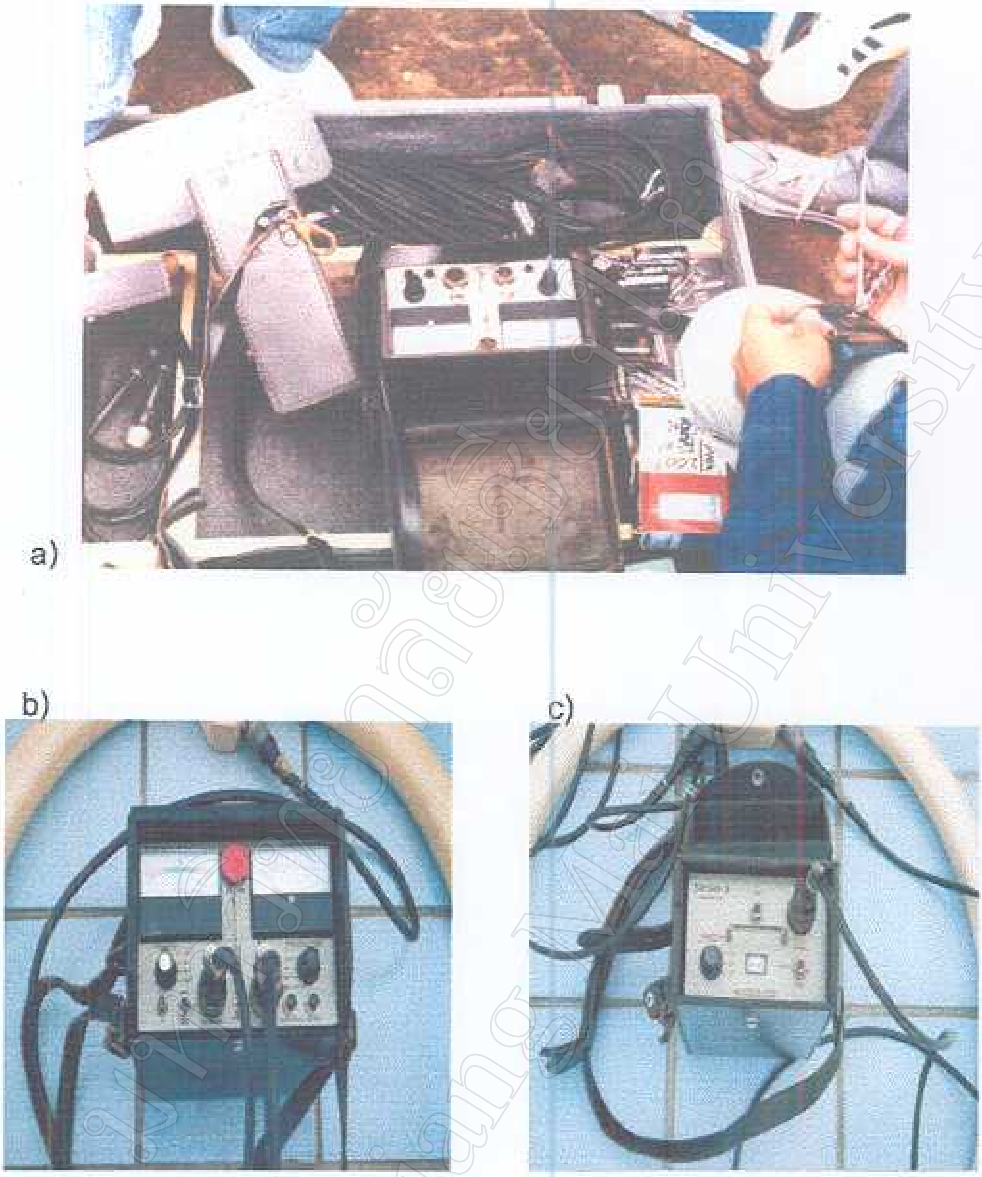
a)

b)

a) A completed set with the resistivity unit (Geonics)

b) A completed set with the resistivity unit (Scintrex)

Figure 2.15 The VLF electromagnetic unit.



a) Terrain conductivity meter

b) Receiver connects to the receiving coil

c) Transmitter connects to the transmitting coil

Figure 2.16 The terrain conductivity meter system

a)

b)

a) EM34-3 is operating in the horizontal dipole mode or co-axial configuration

b) EM34-3 is operating in the vertical dipole mode or co-planar configuration

Figure 2.17 The electromagnetic configuration name time domain system is based on its time dependent as opposite to frequency dependent used in a continuous wave application.

When a circuit is carrying a steady electric current, the constant magnetic flux is produced, vice versa. However, within a conductor, the magnetic flux does not immediately disappear after the current is off. The intensity of the magnetic flux that can be measured after the current is off depends on the conductance of the conductor being induced. At a definite time interval, an amount of magnetic flux measured is used to indicate whether the induced body is a good or a poor conductor.

The transmitter in PEM surveys is a square or a rectangular loop. A known current is sent for a limited time in a loop and then switched off. As soon as the primary field has ceased to exist, the loop is automatically connected to the detecting device. The signal voltage in the receiver is sampled at a suitable predetermined interval from 2 milliseconds to 200 milliseconds. The measured signal is then divided by the primary signal and the values for different times that are stored in a microprocessor. The better the conductor, the longer the eddy current flows in it and the longer is the duration of the secondary field.

The time domain electromagnetic system, Crone PEM, used in the study is a portable one, operating as a moving system for ground survey and fixed loop for bore-hole surveys. The transmitter consists of a powerful pulse generator energized by 24V battery (Figure 2.18a). The receiver is a microprocessor-based gear (Figure 2.18b) and a high precision coil (Figure 2.18c), which can measure both vertical and horizontal magnetic flux a part per million of the primary magnetic field. The result of each measurement can be viewed via a LCD graphic screen and a decision to store each data set can be made. A depth of investigation has to be set prior to any survey by the loop laid out and coil separation distance. Up to 3000m deep can be investigated by this unit if appropriate generator is used (Crone, 1979).

2.3.7 Resistivity survey

Resistivity survey is one of the electrical prospecting designed to yield information or bodies having anomalous electrical conductivity. It is an oldest electrical technique in geophysics, used to map variations in ground resistivity and therefore geology. Resistivity of any rocks is roughly equal to pore-fluid resistivity divided by fractional porosity. Resistivity of common rocks and mineral are between 10 to 10,000 ohm-m (Grant and West, 1965; Telford and others, 1976). The ground resistivity can be measured by passing direct electrical current between a pair of ground electrodes and measuring the voltage between the other pair. The voltage reading is then converted to resistivity depending on its array. Common electrode arrays and their geometric factor can be derived from a)

b)

c)

a) Crone PEM transmitter

b) Crone PEM receiver

c) Crone PEM receiver and the receiving coil

Figure 2.18 The pulse electromagnetic (PEM) system the first principles namely Wenner, Schlumberger, Dipole-Dipole, etc. (Von Nostrand and Cook, 1966).

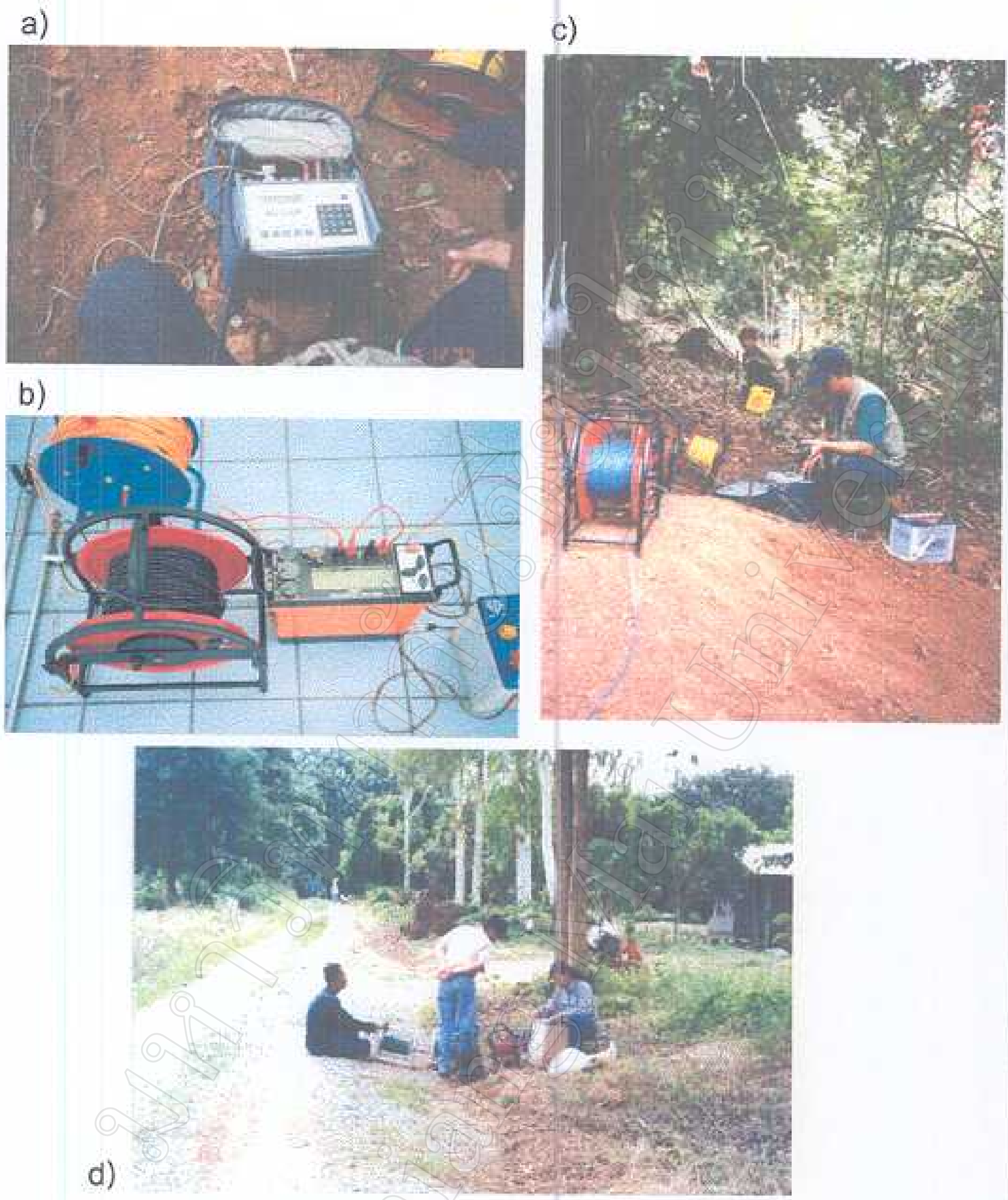
Barker (1981) pointed out that the signal contribution contours of the Wenner array at depth are slightly flatter than the others, suggesting that it will locate flat-lying interfaces more accurately. In contrary, the signal contribution contours for Dipole-Dipole array are the best suite to map lateral changes or vertically oriented structures. Techawan (1995) summarized the advantages and disadvantages for a survey over the geological environment in Thailand and made a model studies suite for conductive overburdens. However, the model studies are widely used in groundwater and engineering applications because detailed informations are obtained under favourable circumstances such as a layered-earth model.

McOHM MARK-2 of OYO Corporation (Figure 2.19) was used in the direct current resistivity (DCR) surveys made in this study. This system transmits output current up to 200V, 200mA, which combined with the stacking functions. For even more current, an optional power booster can boost transmitted current up to 800mA, enough for most resistivity surveys. The stored data can be transferred directly to a personal computer for processing via a normal RS-232 port.

2.3.8 Induced polarization survey

All common sulphide minerals, except sphalerite, are electronic conductors, so are most minerals with a metallic luster, including graphite and some kind of coal (Keller and Frischknecht, 1996). Therefore, minerals other than ore will give an induced polarization (IP) response. A response, geologic noise, is also obtained from some clay minerals that are not electronic conductors but have an unbalanced surface charge. A new work with complex resistivity spectra offers a way to discriminate between signals from ore and non-ore minerals but the final conclusion still has to be verified by other means (Hohmann, 1990).

Normally, dipole-dipole array is used in the IP survey. This array is quite efficient to map in the subsurface geology and a qualitative interpretation can be made easily (Coggan, 1973). Multiple current electrodes are always used in the resistive ground and/or conductive overburden area in order to increase the induced current flow. Two different induced polarization systems, frequency domain and time domain, will be discussed here. In the frequency domain, the resistivity is measured at two frequencies and the polarization is calculated from the difference between resistivity at the two frequencies. A percent frequency effect (PFE), related to metallic mineral content, is expressed in large and more convenient numbers taken from the small numerical difference. A term, metal factor is used to express an anomalous zone. This term is obtained by dividing the PFE with the resistivity of the lower frequency and multiplies by a constant,



a) McOHM resistivity meter

b) Resistivity meter connected with cable and battery

c) Resistivity survey along the line

d) Resistivity survey along the road

Figure 2.19 The resistivity meter.

normally 1,000. The constant serves to put the metal factor into the range of commonly used number.

The time domain IP set is an integrated, microprocessor-based design. The IP data in this study was obtained by IPR-11 of Scintrex, Canada (Figure 2.20a). The system provides a large amount of induced polarization transient curve shape used in an indirect approach, physical properties of rock and mineral. The transmitter consists of a power source, which is a large motor generator connected to an output controller (Figure 2.20c). Voltage levels are selectable within a range of 300 to 1500 volts. Current levels, up to 10 amperes, are controlled and recorded for further resistivity calculation as well as IP effect. The current stability can also be controlled easily by its current stabilizer.

In practice, current direction is reversed after each reading to minimize the effect of natural voltages, and a cycle time can be varied form 1 to 16 seconds. One second each for energization is not sufficient for a reliable result but eight-second interval unreasonably prolong the survey work. Normally two-second cycle is used for dipole-dipole array of 20m - 40m electrode separation. The advantages and disadvantages of each array and their reliability were discussed in details by Techawan (1995).

2.3.9 Comparisons between all ground geophysical methods

Each geophysical technique has a favourable and unfavourable characteristics. Each was designed to investigate a physical parameter measured, comparatively or absolutely, by means of various meters. Geophysicist has to make a decision how to choose the most reliable system to locate and study the specific physical parameter of each target. Not only the geological structure but also their detection capabilities are the key factors for a decision- making. Others are data handling difficulty; labour needed, time and cost effective. Table 2.2 summarizes the geophysical systems used in this study. The listed systems are neither the wholes set nor the best set commercially but they are available and suitable for this study only. Some parameters, time and difficulty levels are set by the author from his own experience.

2.3.10 Appropriate integrated methods for a specific mineral deposit

In this study area, there are many types of mineral occurrences with various physical characteristics. Some are massive and some are stratified. Some are conductive and some can be magnetized. Mineralization processes control each type of these deposits. Since the rugged terrain is the major topography covering this area and accessibility is limited. A specific geophysical system is assigned according to its geological characteristics. The result from each geophysical survey data is then used to outline mineral potential areas and economic evaluation

a) IPR-11, the induced polarization receiver

b) Porous pots

c) TSQ-3, the induced polarization transmitter

d) Record data in the field

e) IP survey along the traverse line

Figure 2.20 The induced polarization meter.

made. Table 2.3 lists the geophysical systems assigned to different mineral deposits in this area.

Table 2.2 Geophysical system used in this study showing their capability and limitation.

Type	Data Handling	Number of operator	Labour	Time (hr.)*	Enhance level **	Interpret level**	Depth to the top (m)
Magnetic	digital	1	none	2	4	3	1000
HLEM	digital	2	5	4	3	4	200
Terrain conductivity	analog	2	4	3	1	1	30
VLF-EM	digital	1	none	2.5	2	2	50
Time domain EM	digital	2	8	5	5	5	300
Resistivity profiling	digital & analog	1	4	5	3	2	60
Resistivity sounding	digital & analog	1	5	6	2	1	100
Induced Polarization	digital	2	10	6	3	5	300

*Time = time used in one line-kilometer over a hilly terrain.
**Difficulty levels for enhance and interpret (defined by author):

1 = very easy;
2 = easy;
3 = moderately difficult;
4 = difficult; and
5 = very difficult.

Table 2.3 Geophysical system assigned to mineral deposits in the study area.

Mineral Type	Geological characteristic	Geophysical system	Remark
Chromite	Podiform, banded and disseminated in U rock	Magnetic	Location only
Nickel sulphides	Podiform and disseminated in U rock	Magnetic and EM	Location and depth
Garnierite	Weathering product of Ni mineral in U rock	Resistivity and Magnetic	Depth and boundary
Talc	Alteration product of mineral in U rock	Magnetic and EM	Location and boundary
Asbestos	Alteration product of mineral in U rock	Magnetic and EM	Location and boundary
Iron ore	Weathering product of iron-mineral in U rock	Magnetic	Location and boundary
Illite	Alteration product of mineral in volcanic rock	EM	Location and boundary
Graphite	Metamorphosed product of carbonaceous mineral	EM and IP	Location and orientation
Actinolite	Metamorphosed product of mineral in U rock	EM and Magnetic	Location and boundary
Sulphides	Vein type or skarn deposits	Magnetic and EM	Location and orientation
Gold	Auriferous granitoid (felsic/coarse grained)	Magnetic and spectrometry	Location and boundary
Construction material	Weathering product of mineral and rock	Resistively and EM	Depth only

U = Ultramafic; EM = Electromagnetic; IP = Induced Polarization