# Chapter 4
# Methods

## 4.1 Aeromagnetic data

The interpretation of magnetic anomalies over these geological regions is expedited by the development of special techniques for the detailed analysis of magnetic anomalies. Much large variation in crustal magnetic susceptibility allows the interpretation of observed magnetic anomalies, but this is often complicated by the variation of the anomalies with respect to their sources.

Many processing methods have been developed for improving the estimations on depth of magnetic sources, the magnetization of the source material, and the geometry of the bodies. However, all processing methods suffer from the fact that no unique magnetization distribution can be found for a given set of observations. A number of techniques have been successful in predicting source characteristics, using certain assumptions.

Enhanced magnetic techniques have been created to display more detailed information from the raw data by several authors. Milligan and Gunn (1997) described the enhancement and presentation of airborne geophysical data by using linear and non-linear filtering algorithms that selectively enhanced anomalies due to one group of geological sources relative to anomalies due to other groups of geological sources. Tarlowski et al. (1997) demonstrated the enhancements on the magnetic map of Australia. The enhancements of the total magnetic intensity image are including vertical gradient, upward continuation and reduction to the pole. Gunn (1997b) illustrated the detail of quantitative methods for interpreting aeromagnetic data. The depths of magnetic source were determined by using the characteristics of profile data and automatic inversion programs. Furthermore, he described the regional magnetic and gravity response of an extensional sedimentary basin and explained the evolution of extensional sediment basin compared with the characteristic of magnetic and gravity responses in each stage.

Many enhancement techniques, such as reduction to the pole, vertical derivative, analytic signal, upward continuation, automatic gain control, and directional cosine filter were applied in this study. Each technique helps to display the edges of magnetized bodies and lateral contrasts in magnetization, which are mainly caused by lithological and structural changes in the buried basement. The image maps of the source edges are initially used to group trends that have similar orientation. Interpretation of areas that have comparable anomaly amplitudes, and patterns, then domain boundaries and regions can be drawn. The boundaries are then mapped more accurately using the source edge maps by placing margins at the position of source edges coinciding with major amplitude changes. The enhancement methods are described below.

#### 4.1.1 Data enhancement methods

##### 4.1.1.1 Reduction to the pole (RTP)

Shapes of any magnetic anomaly depend on the inclination and declination angles of the main magnetic field of the Earth relative to the magnetization of the source. The same magnetic body will produce a different anomaly depending on where it happens to be in the Earth's field. In the case of an area has inclined Earth magnetic field (low inclination), the significant anomalies are shown by a couple of high and low magnetic intensities forming a dipole. In contrast, in the area of vertical Earth magnetic field, the magnetic anomalies are only shown by the high magnetic amplitude of the vertical bodies.

Reduction to the pole (RTP) is the process of converting the magnetic field from a magnetic latitude where the Earth's field is inclined, to the field at magnetic pole, where the inducing field is transformed to vertical. The RTP filter reconstructs the magnetic field of a data set as if it were at the pole. This means that the data can be *viewed in map assuming a vertical magnetic inclination and a declination of zero* (Milligan and Gunn, 1997).

As a result, RTP greatly simplifies the interpretation of magnetic data. In this way, the interpretation of the data is made easier than what the raw data maps. The high magnetic boundaries are more accurately positive, because the vertical bodies will produce induced magnetic anomalies that are centered on the body and are symmetrical. However, reduction to pole has a problem where the survey area is setting at very low magnetic latitude (shallow inclination). Since, the study area has the inclination about 22 degrees, the reduction to the pole may be affected by the data processing. The detail of this problem and the solution for keeping this effect will be described in the next Chapter.

**4.1.1.2 Vertical derivative**

Vertical derivative or vertical gradient technique is used for locating the edges of magnetic source bodies after a transformation in the frequency domain that converts magnetic anomalies by multiplying the amplitude spectra of the field by a factor of $1/n$ $[(u^2+v^2)^{1/2}]$, where $n$ is the order of the vertical derivative. The operation shows that the process enhances high frequencies relative to low frequencies and this property is the basis for the application of the derivative, which eliminates long wavelength regional effects and resolves the effects of adjacent anomalies. On the other hand, vertical derivative (1$^{st}$or 2$^{nd}$derivatives) amplifies short-wavelength information at the expense of long-wavelength information, accentuates gradients along the edges of shallow magnetic sources, and emphasizes sources at shallow depths (Milligan and Gunn, 1997).

The first vertical derivative data have become almost a basic necessity for magnetic interpretation. The second vertical derivative has even more resolving power than the first vertical derivative, but its application requires low noise data as its greater enhancement of high frequencies results in greater enhancement of noise.

This study applies the first and second vertical derivative with automatic gain control (AGC) (described below) for increasing the vertical continuity of magnetic source bodies. These methods can be used for locating the detailed structural geology (lineaments) of the area.

#### 4.1.1.3 Analytic signal

Analytic signal of magnetic anomaly is a combination of the vertical and horizontal magnetic derivative (Roest et al., 1992). It has the useful property of being independent of the magnetization direction of the causative body. As in the case of the vertical derivative, the analytic signal exhibits a maximum at the edge of magnetic source body. Theoretically, variation in dip along the edge has no effect on the location of the maximum. Hence, computing the analytic signal and locating its maxima is an efficient way of mapping the top edge of bodies independent of magnetization orientation and dipping contacts. This means that all bodies with the same geometry have the same analytic signal. Furthermore, as the peaks of analytic signal function are symmetrical and occur directly over the edges of wide bodies and directly over the centers of narrow bodies, interpretation of analytic signal maps and images should, in principle, provide simple, easily understood indications of magnetic source geometry.

The computing of the analytic signal (Roest et al., 1992) is a function related to magnetic fields by the sum of derivative as follow:



Analytic signal: $|A(x,y)| = \{(\partial m/\partial x)^2 + (\partial m/\partial y)^2 + (\partial m/\partial z)^2\}^{-2}$



where m = magnetic anomaly

Analytic signal maps and images are useful as a check for reduction to the pole, as they are not subject to the instability that occurs in transformations of magnetic fields from low magnetic latitudes (MacLeod et al., 1993). It also defines source position regardless of any remanence in the sources.

**4.1.1.4 Downward/upward continuation**

Upward and downward continuation is a computation of fields at higher or lowers magnetic survey levels. The process has response of $e^{-h (u+v) 1/2}$. This means that upward continuation smoothes out high-frequency anomalies. The process can be useful for suppressing high frequency anomalies caused by noise and near surface sources. Downward continuation sharpens the effects of anomalies (enhances high frequencies) by bringing them closer to the plan of observation or it simulates flying the survey closer to the ground. In practice, high frequency noise is enhanced as well as the geological anomalies, and it is normally difficult to continue a field downward very far. The practice limits depend on the sample interval and the quality of the data set. In this way, the downward continued anomalies will have less spatial overlap, and thus are more easily distinguished from one another. This process also increases the amplitude of the anomalies. However, some of the short wavelength signals are due to shallow sources, and problems will occur if one downward continues through these shallow sources. Therefore, the short wavelengths noise or sources must be removed prior to downward continuation by applying a low-pass filter such as the Butterworth filter. Plot the radial average energy spectrum to determine the wavelength at which the sources (noise) appear to be shallower than the depth of continuation. A similar effect is achieved using the upward continuation, except that the measurement plane is further from the sources, and fewer side effects are produced.

Upward continuation is stable, but downward is not since short-wavelength noises are amplified exponentially. To remedy this, data should be band-pass filtered to remove the short-wavelengths before downward continuation. Upward continued field may reflect the regional field and upward field bring deeper anomalies more focus.

**4.1.1.5 Automatic gain control**

Automatic gain control (AGC) converts waveforms of variable amplitude into waveforms of semi-constant amplitude. The net result is the removal of amplitude information from data set, producing a representation of the data that gives an equal emphasis to signals with both low and high amplitudes. AGC stacked profiles

(Rajagopalan, 1987; Mudge, 1991) and images (Rajagopalan and Milligan, 1995) are extremely useful for structural mapping because they trend to show coherent alignments not apparent in true amplitude data.

Automatic gain control processing creates an image in which all anomalies are constrained to have approximately the same amplitude and weak features are, in principle, equally as evident as intense features. Although amplitude information is destroyed in such a process, the results are extremely useful for structure interpretation (Gunn et al., 1996).

#### 4.1.1.6 Directional cosine filter

The directional cosine filter is very good for removing direction feature from a grid in one direction and enhancing the right angle direction. The cosine function makes the filter smooth, so directional ringing problems are usually not a problem. The rejection (or pass) notch can be narrowed or widened by setting the degree of the cosine function so that highly directional features can be isolated (Oasis Montaj, 2001).

### 4.1.2 Interpreting magnetic methods

Several interpretation methods were applied with the final goal of enhancing the signature of fault and rock boundary units. Magnetic data can be displayed as a profile or in a map. The interpretation for the two cases is different One of the most important thing to remember when analyzing magnetic data is that many interpretations may fit the observed data. For this reason it is always helpful to have other data to constrain the interpretation, i.e. geological information.

Gunn et al. (1997) mention the interpretation methodology consisted of inspection of computer screen and hardcopy image, maps of the aeromagnetic data, and other relevant data to define:

- *Boundaries of magnetic units,*
- *Structures dislocation or affecting the morphology of magnetic units,*

- *Depth and attitude of magnetic units,*
- *Any superposition of magnetic units, lithological units,*
- *Chemical change, and*
- *A structure synthesis relating distribution of inferred lithologies and structure.*

The main resulting display data can be provide in form of profiles and contour maps.

Profiles are best taken perpendicular to the strike of the anomaly. They can be used to identify zones with magnetic sources, get an indication of dip by comparison with master curves, and get an idea of relative intensities. After removing the regional trend, perform a quantitative interpretation is performed to determine possible depth, shape, size, and magnetization of local anomalies.

Contour maps can be used to correlate low/highs magnetization to known geology and can be correlated with lows/highs in gravity map. Furthermore, they used to look for structural features represented in the contours and look for trends and identify area with no known source for magnetic characteristics.

A chart that summarizes the steps taken when analyzing magnetic data is shown in table 4.1.



Table 4.1 Magnetic characteristic and possible cause effects.

| **Applies to:** | **Magnetic character** | **Possible cause** |
|---|---|---|
| Segments of a Profile/area of map | Magnetically quite/noisy | Susceptibility of near surface |
| Anomaly | Wavelength | *Short-near- surface feature*<br>Long-deep-seated feature |
| Anomaly | +/- Amplitude | Indicates intensity of magnetization |
| Profile/maps | Anomaly structure | Indicates possible dip and dip |

| | | |
|---|---|---|
| | and shape | direction |
| Profile/map | Magnetic gradient | Possible contrast in susceptibility and/or magnetization direction |
| Maps | Linearity in anomaly | Indicated possible strike of magnetic feature |
| Maps | Dislocation of Contours | Lateral offset by fault |
| Maps | Broadening of Contour interval | Downthrows of magnetic rocks |

(*From gravity and magnetic: GOPH547, Laboratory of Department of Geophysics, University of Calgary, Canada*).

The detail in total magnetic data, supplemented by the range of enhanced map and image products typically produced to display these data, normally provide an excellent basis for qualitative interpretation in which geological boundaries and lithologies are visually estimated. Interpretation of this type, which in effect, producesoutcrop or sub-outcrop maps, are routine for areas where all magnetic units occur at or near the ground surface and when anomalies are relatively discrete.

Where magnetic rocks occur at variable depth or beneath substantial non-magnetic cover, and where it is essential to know the depth to the magnetic sources, quantitative depth determinations are required. In some cases, specific details of geometry and magnetic properties of the magnetic sources are required and complete quantitative interpretation of magnetic anomalies must be undertaken.

**4.1.3 Modeling method**

Modeling provides a tool for integrating magnetic and other data, such as gravity, seismic, exploration well and surface geology. Using modern software on PC-based modeling tool, interpreters can easily test a wide range of geologic models and examine the sensitivity of the magnetic and gravity response to the variation in those geologic models.

This study uses the Modelvision inversion program (described in the next section) for determining the geometry of the magnetic sources. The automatic inversion routines that produce a geological model, the magnetic affects of which match an observed magnetic data set. The inversion program can be divided to linear and non-linear inversions.

**4.1.3.1 Linear inversion technique** (Bott, 1976; Safon et al., 1977) consists of sub-dividing the space below in observed magnetic field into a series of geometric bodies and then finding values of the magnetization for the shapes, such that the summed magnetic effects of all the bodies matches the observed magnetic field. The linear inversion program was used to select profiles across an anomaly and produce match at several locations between observed and calculated data.

**4.1.3.2 Non-linear inversion technique** (Al Chalabi, 1970; Mc Grath and Hood, 1973; Gunn, 1997) attempts to obtain a match between observed and calculated magnetic fields by interactively varying unknown parameters, such as the coordinates of model bodies and magnetization. Using a trial and error method, variations that improve the fit between the observed field and calculated results based on the model are stored and used as a basis for new parameter estimates.

## 4.2 Other geophysical methods

### 4.2.1 Electromagnetic method

Because of the large survey area, so electromagnetic data in xyz format are divided into 12 xyz files included data each in each channel such as x, y, In-phase and quadrature of the frequencies 736, 912 and 4200 Hz, and apparent resisitivity of the 4,200 Hz data. The data processing of EM data is displayed in grid image that can be overlain with the other data by using the GIS technique. The software program for data processing is ChrisDBF software. The processing steps of electromagnetic data are as follow:

- Create the *database file* by open each xyz file. Input the name of each channel and save the format channel name created the dbf file.
- Add the name of data file by using *Inter Channel Arithmetic*. The name for data file should be the same name of each xyz file.
- Export each database file to *Ascill format (.csv)*, and select the format in comma delimited.
- Merge files.
- Process *first vertical derivative* in each channel data for smoothing and set the data to the same level. All data will move to the zero level. This technique apply to decrease the leveling problem and compress anomaly wavelength.
- Create grid by using the *Spline grid method.* This grid method is useful for line sampled data. It can be reduced the Trend Enforcement Gridding problem. A *mesh* of size 100 and scan *dish* distance of 1000m was used for this survey.
- *Display grid* and checking the quality of line data. If some line data have a problem (bad data), we can edit or ignore the bad line data by choosing the line data in *display channel* command. The bad line data will delete, then create grid again.
- In apparent resistivity grid image, we convert to conductivity grid image by calculating conductivity =1/resistivity.
- Because the anomaly in HEM will show the negative amplitude, so in the in-phase and quadrature grids are multiply by –1 to convert the data to high amplitude anomaly.
- Use *ER Mapper software* for processing the image by changing the *algorithms* and create *RGB color composite* of combination of the three data sets.

### 4.2.2 Remote sensing method

Remote sensing images display a significant role in defining geological structures and tectonic fabrics of the study area represented by lineaments that are deciphered primarily using satellite imageries. The remote-sensing images have been acquired in digital forms as two-dimension arrays or raster made up of pixels (picture elements). A digital number that represents the energy of the electromagnetic radiation waveband being monitored assigns each pixel correlated with the brightness level of that pixel in the image. These type of digital image are referred to as raster images in which the pixels are arranged in rows and columns

An image processing of remote sensing normally consists of three main steps, namely, rectification, enhancement and data extraction. The rectification is here in used to improve correspondence of image data within the represented scene. The enhancement step is normally undertaken to improve ability to identify features of interest in the imagery. The data extraction step is used to interpret and classify each project such as land cover and geology. The detailed explanation for each step can be found in Neawsuparp and Charusiri (2000). In this study, only the enhancement for structural analysis is involved.

#### 4.2.2.1 Image enhancement methods

Image enhancement is an operation designed to optimally display information from imagery data for visual interpretation. An image usually contains more information to be displayed in a single picture. The image enhancement entails selection of the subset of information to be displayed as well as the optimum display of that information.

One of the strength of image processing is to gives the ability to enhance the view of an area by manipulating the pixel values, thus making it easier for visual interpretation.

In this study, the digital images from Landsat TM 5 are processed and displayed using the two main programs namely IDRISI and ER Mapper programs (described in next section) and remote sensing image enhancements are applied as following:

*4.2.2.1.1 Contrast stretching*

Contrast stretching is valuable in enhancing Landsat data. Because the exposure time in the Landsat is not variable, and the sensitivity of the instrument must be set so those scenes of different albedo do not saturate the sensor. Contrast enhancement involves changing the original values so that more of the available rang are used; this then increases the contras between features and their backgrounds.

*4.2.2.1.2 Directional filters*

Directional Filters are designed to enhance linear features such as roads, streams, faults etc. The filters can be designed to enhance features that are oriented in a specific direction, making useful for geological applications. Directional filters are also known as edge detection filters.

Directional filters are applied to image using a convolution process by mean of constructing a window normally with a 3x3 pixel box. The directional filters can be applied in order to highlight lineaments by controlling the sunlight direction in cross with the main structural geology.

*4.2.2.1.3 False color composites*

Landsat TM produces 7 digital bands of electromagnetic energy. These images can be processed individually to enhance the image, but they remain gray level images of the scene. It is possible to colorize a scene by applying a color to a selected band so that for example: band 1=Bbue, band 2=green, and band 3=red. This produces a 'false color' RGB image of the scene.

*4.2.2.1.4 Principal component analysis*

Principal component analysis (PCA) is a coordinate transformation typically associated with multi-band imagery. PCA reduces the redundancy contained within the data by creating a new series of image components in which the axes of the new coordinate systems point in the direction of decreasing variance. The resulting components are often more interpretable than the original image.

#### 4.2.3 Radiometric method

Gamma rays are measured in counts per second for each radioelement. Most survey data are calibrated into percent K and parts per million (ppm) for Th and U. Gamma ray data are display as images which readily enhanced for distinguishing soil/regolith materials. Pseudo-color of three band composite image, with K in red, Th in green and U in blue were created in this study.

#### 4.2.4 Gravity method

Most of gravity stations were outlying the Loei area. Dense station spacing was measured on the road cut in southern part of Loei area. The database was used to interpretation are displayed as image generated a 5'x5' grid (approximately 10 x 10 km). These data can be only use for identify both high and low densities trend at the scale of 1:1,000,000, and was not used in this study for a scale of 1:100,000.

#### 4.2.5 Digital elevation method

Digital elevation models (DEM) provide information on important geomorphic variables, including elevation, slope, aspect, convexity and relief. The accuracy of these variables largely depends on the spatial resolution of DEM data. The variables have a controlling influence on geomorphic processes and distribution of soil/regolith materials. DEM image is produced by using the digital contour map data from a scale of 1:250,000, and displayed as color relief image. Randomly located digital contour data were gridded using minimum curvature. This display facilitates the visualization of complex relationship between the gamma-ray response and terrain morphology attributes.

### 4.2.6 Magnetic susceptibility method

A rock-sampling program was carried out in the area to determine the magnetic susceptibility level for each rock type. Rock outcrops were chosen from the existing geologic map to ensure that each rock unit was sampled. Each rock sample was cut as cube shape (1"x 1" x 1") and measured the magnetic susceptibility and density in laboratory. No oriented rock samples were collected, and magnetic remanence was not measured.

## 4.3 Software application

All of the data used in this study are now available in digital format. There are a variety of grid data types and formats that mainly depend on the software employed in the processing. The most efficient system use software packages with compatible data type and grid format, so that conversion between formats is not necessary. The processing methods for this study can be divided to four applications.

### 4.3.1 Enhancement

A wide rang of tools are available for modern PC-base software to enhance the geophysical data to focus on upper crustal structure. Interactive PC-base software provides efficient tools for geophysical dataset.



### 4.3.2 Modeling

Modeling provides a tool for integrating geophysical data with surface geology. Using modern PC-based modeling tools, interpreters can easily test a wide range of geologic models and examine the sensitivity of the magnetic response to variation in those models.

### 4.3.3 Remote sensing data

When remote sensing data are available in digital format, digital processing and analysis may be performed using computer software. Digital processing may be used to enhance data as a beginning to visual interpretation. Digital processing and analysis may also be carried out to automatically identify targets and extract information completely without intervention by human interpreter. One of the strengths of image processing is that it give me the ability to enhances the view of an area by manipulating the pixel values, thus making it easier for visual interpretation

### 4.3.4 Geographic information system

Geographic information system (GIS) is computer program for managing and integrating spatial data, maps, digital image and geo-reference data in table. For this study, data for GIS conclude geology, topographic, mineral occurrence, geophysics, and satellite image. Modern GIS computing software and relational data set are provided a unique situation for analysis of geological information by rapid digital integration of multiple data seta as layers in a map.

Software for enhancing and modeling geophysical and remote sensing data that will be used to analyze the data are summarized in Table 4.2.



Table 4.2 Software programs used for application in this study.

| Application | Software programs |
|---|---|
| Enhancement and data processing | ChrisDBF (11.37), Oasis (5) |
| Magnetic modeling | Modvision Pro (4.0), |
| Landsat processing | ER Mapper (6.3) |
| GIS data integration | Arcview (3.2) |

Brief of all software systems for using in this study is shown in Appendix I. All of the research methods in this study are shown in Fig. 4.1.

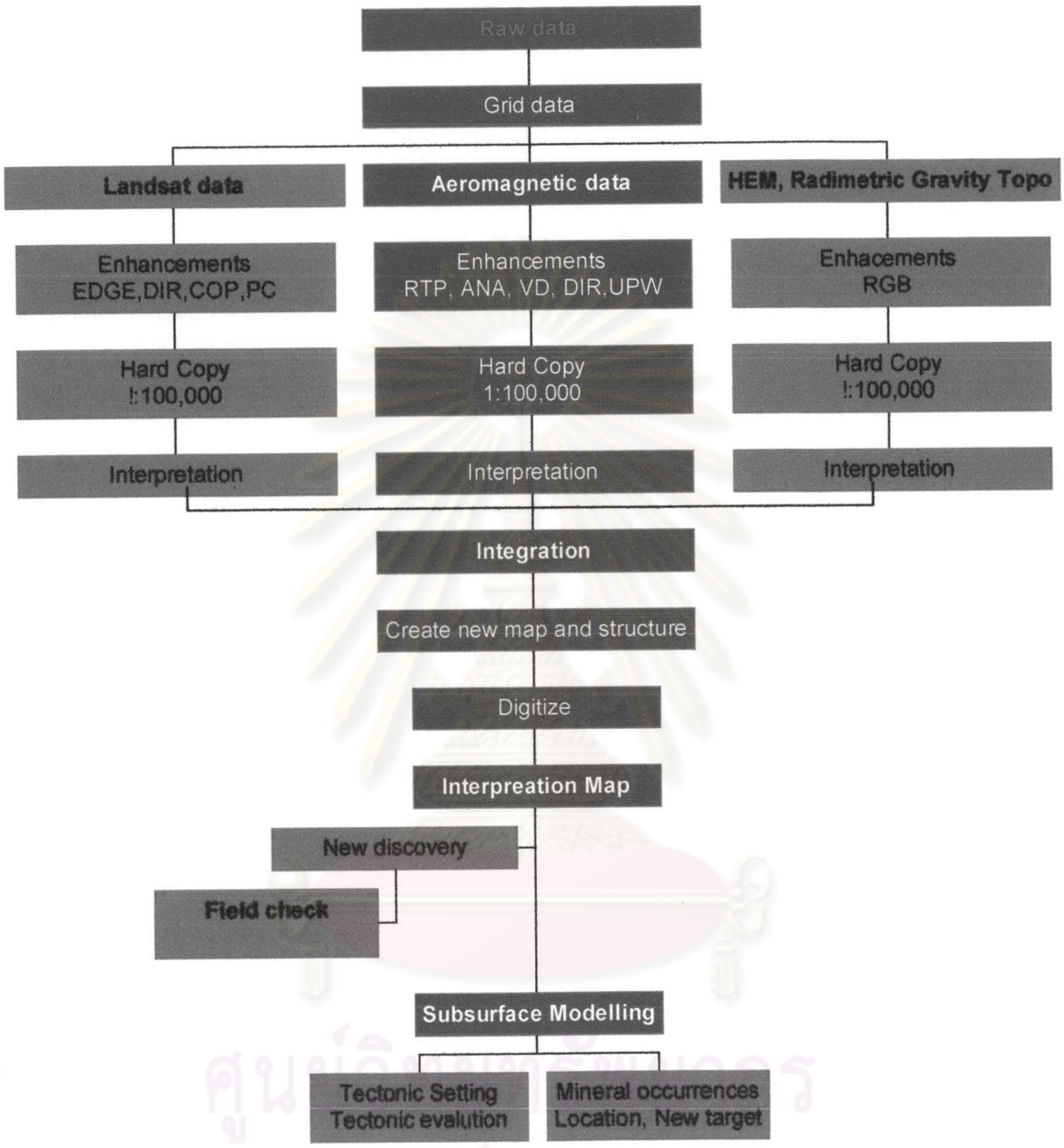




Figure 4.1. Flow chart showing the research methods in this study.