Chapter 5
Experimentation with Magnetic RTP

5.1 Issues with low latitude TMI response

Enhancements of original aeromagnetic data are very important for the magnetic interpretation, especially in the complex information area. Basic interpretation of the aeromagnetic data set was performed on various image of the data set reduction to the pole (RTP).

Reduction to the pole is the converting operation for the magnetic field at the latitude where the Earth's magnetic field is inclined is transformed to the field at a magnetic pole, where the inducing field is vertical. Where the Earth's field is an inclined, magnetic anomaly (induced field) having forms as asymmetrically related to their sources, but when the inducing field is vertical, the induced anomalies are directly over their sources as long as there is no strong remanence (Milligan and Gunn, 1997). The interpretations of magnetic data using the reduction to the pole technique are clarified, because at low magnetic latitudes the anomalies related to the source geometry are often not apparent. Such maps and images are significantly easier to interpret than original data sets in areas of significant magnetic inclination.

Unfortunately, the RTP operation has a problem for areas of very low magnetic latitude, because the Fourier domain transformation process becomes unstable, owing to the need to divide the spectrum by a very small term (Macleod et al., 1993). To solve this problem, some workers limit their transformations to greater than 15° and accept the result. Others approximate the process by doing two transformations for smaller amounts, where the sum of the angle involved in the transformation equals the difference between the survey latitude and the pole. Some workers avoid the issue altogether by performing a reduction to the equator. Gunn and Almond (1977) have demonstrated a space domain solution to the problem of transformation at low latitude.

Thailand area is sitting at very low magnetic latitude between -6° to 26° N from southern to northern parts of the country, with approximately less than 1° declination. Although the inclination of the Loei area is at 22° N, an effect occurs during for the RTP processing.

5.2 Artifacts Associated with Data Filtering

The characteristics of magnetic field responses at low magnetic latitude are included three main effects:

- N-S "stretching"
- Predominant negative responses, and
- Suppressed amplitudes.

The suggestion of Isles (1990) is that these effects are mainly involved with correlation procedures in aeromagnetic gridding algorithms that usually have a strong across-line bias. The desirability of NS orientation of flight lines combined with the NS stretching effect can result in inappropriate correlation between lines generating "beading" effects in contour maps. The selection of gridding parameters should take this into account, for example, rectangular grid or re-orientation of search ellipses. A general rule, the problems will diminish with closer line spacing. Both line direction and line spacing need careful consideration at low latitudes.

Isles (1990) described two problems occurring with RTP. One was the instability of the operation when transformation from inclinations of less than around 15°. This is usually manifested as NS "striping" in the RTP result. His experience has shown that performing the RTP in stages involving rotation of inclination by no more than 30° can minimize this effect. He also suggested that using a slightly higher original or source inclination than the observed (e.g. 3° instead of 0°, 8° instead of 5°) might diminish the instability with out substantially changing the RTP result.

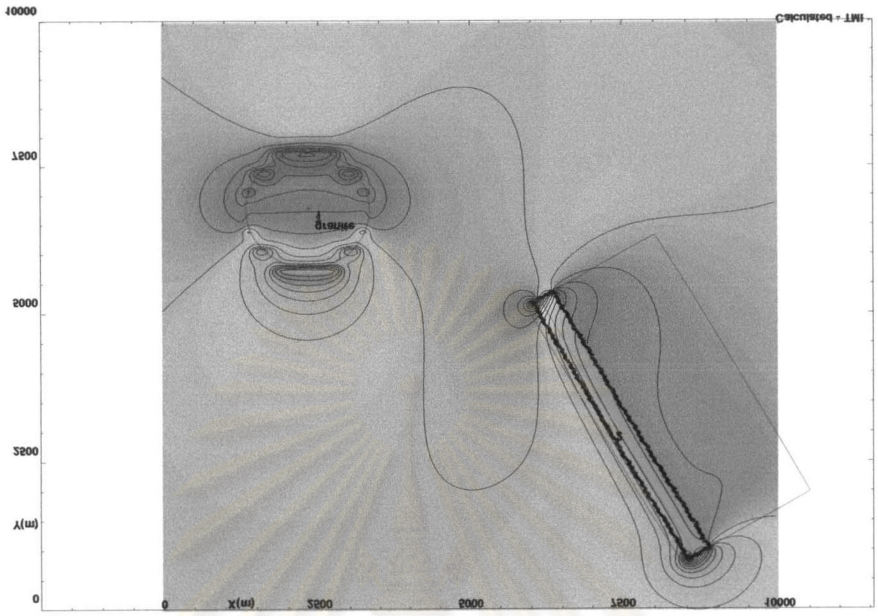
The second problem is caused by the interference effects of sources with different depth ranges. When reduction to the pole generates spurious features of long wavelength response occurred within the survey area. This raises two issues; the first is that *extra survey coverage around* the planned survey area is highly desirable when RTP is to be performed. The second issue is that RTP will perform best when "focused" on the simplest possible data set. Data sets containing responses from a number of depths require filtering to isolate the features of interest prior to or in conjunction with RTP.

Interpretation of magnetic data at low geomagnetic latitudes is more difficult than at high latitudes, since anomaly maxima are not located directly over the causative bodies. This is easily done in the frequency domain using standard linear filtering techniques. However, at low geomagnetic latitude, the reduction to the pole operator amplifies the noise present in the data and produces unacceptable artifacts.

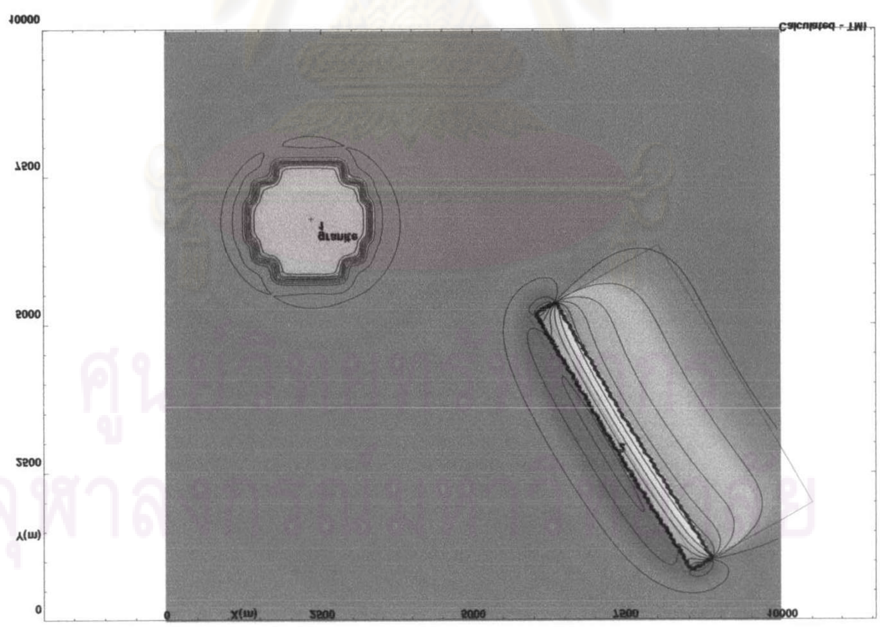
5.2.1 Forward modeling and RTP tests

Although the Loei study area is at the latitudes 17°-18°, and inclination angle 22°, the noise effects at low latitude still occurred during the RTP process. Fig. 5.1 shows the example forward modeling of circular and cylinder bodies with moderate-angle eastward dipping by using the inclination value at 22°. As shown in Fig. 5.1 A, displays the total magnetic field responses indicate dipole magnetic intensity of circular and cylinder features . The purpose of the reduction to the pole is to compute the anomaly that would be served if the field were vertical, usually assuming perfect induction for simplicity as shown in Fig. 5.1B. The induction magnetic intensities is located at the circular and cylinder features, so they are easily to identify the location and boundary of magnetic body.

Fig.5.2 shows the RTP processing of the circular and cylinder features. As shown in Fig. 5.1 A. the circular feature is easy to interpret as an intrusion from a good RTP result, since the dipole magnetic intensity become monopole. However, the cylinder feature shows the distortion of N-S stretching and negative amplitude, which is difficult to analyze and interpret. Therefore, from the Loei study area, we should look for some other methods for solving these problems of the RTP processing before applying the other enhancements.



(A)



(B)

Figure 5.1 Forward modelling of circular and cylinder magnetic feature as in the Loei study area showing

(A) dipole of total magnetic responses of circular and cylinder features at the inclination of 22° , and

(B) the realistic idea for RTP result at the inclination of 90°.

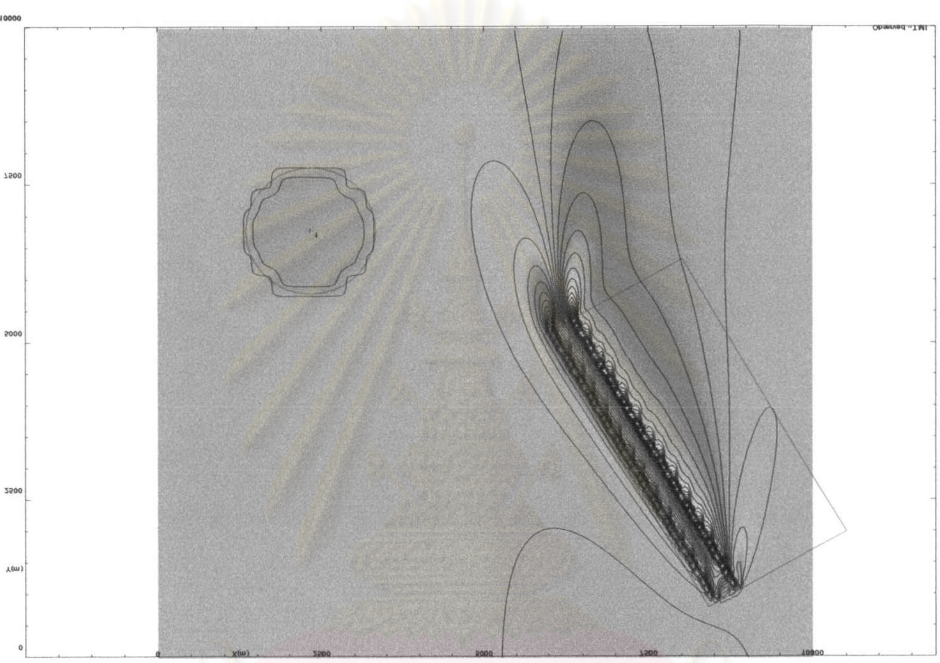


Figure 5.2 Forward modelling of the RTP process using the inclination 22 $^{\circ}$ showing the distortion at the cylindical feature.

5.3 Preferred solution

Many methods to overcome the problem have been suggested by several authors. The followings have been reported in studies of method for solving the problem of reduction to the pole:

Baranov (1957) presented the reduction to the pole technique in an effort to get rid of magnetic anomalies of the complicating patterns due to the oblique angle of magnetization and anomaly projection. A procedure for the numerical calculation of the reduction to the pole formula was given in Baranov and Naudy (1964). As they mentioned, when the inclination of the geomagnetic field was close to zero, structure in north-south direction did not produce any anomaly except at their extremities. However, his process was not honest at low magnetic latitude, because of the very large amplitude corrections that must be applied to north-south trending features.

Bhattacharyya (1965) presented an improvement of Baranov's approach. The magnetic field was expanded in double Fourier series on a rectangular grid. The double integration then could be made analytically instead of numerically. However, the basic problem of instability at low latitudes was still remaining.

Following the work of Bhattacharyya (1965) and coming of Fast Fourier Transform (FFT), most workers have been treating this problem as a simple filtering operation performed in the wave number domain by multiplying the Fourier transform of the observed magnetic field with the RTP operator in the wavenumber domain. As the magnetic latitude approaches the equator, however, the operator becomes unbounded along the direction of magnetic declination and therefore increases the noise in this direction to the extent that the resultant RTP field is dominated by linear features aligned with the direction of declination. To deal with this difficulty much effort has been spent on formulating the stable approximations of the RTP operator. Most workers have focused on a stabilized operator without regards to the actual.

Pearson and Skinner (1982) suggested a reduction to the pole procedure in the wave number domain that operated on the spectrum of the data previously smoothed by a user defined whitening factor. The aim of this whitening factor was to attenuate the noise content in the original data so that noise distortion in the reduced field was minimized. This approach was an attempt to deal with the instability of the reduction to the pole procedure at low magnetic latitudes.

Siva (1986) proposed solving the problem in the space domain using the equivalent, source method. The results were excellent, but the method was computationally intensive.

Hansen and Pawlowski (1989) developed an elegant method in which a Wiener filtering technique was used to form a regularized RTP operator. The important attribute of their work was that the stabilization of the operator was carried out in accordance with the noise in the observed field in the form of an estimated noise power spectrum. However, their approaches, and others in the literature, are based upon filtering, and little emphasis is placed upon being able to reproduce the observed data.

Mendonca and Siva (1993) stabilized the reduction to the pole operator by truncating its Taylor series expansion and reducing the effects of noise by upward continuation of the magnetic field.

Keating and Zobo (1996) presented a technique, base on a deterministic noise model that allowed me to fully automatism, the method developed by Hanson and Powlowski (1989). The resulting reduction to the pole map was further improved by iterative minimizing the residuals between the observed field and the field obtained by projecting the reduced to the original geometric latitude. They stressed the need for better fit between observed and reproduced data as a factor to improved RTP results. Despite much of the effort, the existing RTP procedure still works only with moderately low magnetic latitudes.

Reduction to the pole can be calculated in the frequency domain using the following operator equation 5.1 (Grant and Dodds, 1972):

$$L(\theta)= \frac{1}{[\sin(I)+i\cos(I)\cos(D-\theta)]^2} \quad (5.1)$$

where

θ is the wavenumber direction;

I is the magnetic inclination; and

D is the magnetic declination.

From Equation 1, it can be seen that as I approaches 0 (the magnetic equator), and (D-θ) approaches $\pi/2$ (a north-south feature), the operator approaches infinity.

The very large amplitude correction required for north-south features at low latitude also increases the north-south components of noise and magnetic effects from the inducing field. Numerous authors have addressed the noise problem in the published literatures.

The methods either modify the amplitude correction in the magnetic North-South direction using frequency domain techniques (Hansen and Pawlowski, 1989; Mendonce and Silva, 1993), or calculate an equivalent source in the space domain (Silva, 1986). The simplest and most effective technique is that developed by Gant and Dodds (1972) in the development of MAGMAP FFT processing system. They introduced a second inclination (I') that was used to control the amplitude of the filter near the equator as shown in equation 5.2.

$$L(\theta)= \frac{[\sin(I)-i\cos(I).\cos(D-\theta)]^2}{[\sin^2(I')-i\cos^2(I').\cos^2(D-\theta)]\,[\sin^2(I)-i\cos^2(I).\cos^2(D-\theta)]} \quad (5.2)$$

if $(|I'|<|I|)$, $I'=I$

In practice, (*I'*) is set to an inclination greater than the true inclination of the magnetic field (or less than the true inclination in the southern hemisphere). By properly attenuating the complex amplitude, while not altering the complex phase from Equation 1 to Equation 2, anomaly shapes will be properly reduced to the pole, but by setting |*I'*|>|*I*|, unreasonably large amplitude correction are avoided. Controlling the RTP operator then becomes a matter of choosing the smallest *I'* that still gives acceptable results. This will depend on the quality of the data and the amount of non-induced magnetization present in the area under study.

In Thailand, Tulyatid (1995) studied the problem of reduction to the pole by selecting the test area (strip) and test RTP operation on the data to cross check of the RTP result that corrected to the anomaly position. Results of this step can be used to set up a proper set of I' to be applied to the different part of the nationwide aeromagnetic grid of Thailand. He found that the proper secondary inclination (*I'*) in northern part and southern part of were 60° and 90°, respectively. The interpolation between 60° and 90° are presented in all part of Thailand as shown in Fig. 5.3.

5.4 Comparison of the magnetic reduction to the pole in Loei area

For this study, OASIS and ChrisDBF software programs were selected to compare the RTP results. The producing images are shown in color grid, so it is a good for comparative studies. The aeromagnetic field was done in the Loei province, northeastern of Thailand. The magnetic field inclination and declination are 22° N and -1°, respectively. At this latitude, the pair of different magnetic intensities (low and high) represents the anomalies.

In the method for test the RTP result in this study, the first inclination is fix at 22° (magnetic inclination angle of The Loei area) while the second inclinations are applied in 22°, 30°, 45° and 60°. Displayed results at the different second inclination from two software programs are considered in the case of NS “stretching”, predominant negative response, and suppressed amplitudes.

Fig. 5.4(a) shows the relative residual (IGRF corrected) magnetic intensity magnetic anomaly map of the Loei area presenting a rather complex magnetization pattern. The residual intensity aeromagnetic map exhibits a north-south trending grain agreeable with the surface geological terrain. The most prominent low magnetic intensity is in the center part continuing northward to the boundary between Thailand and Lao PDR. Higher magnetic intensity in the eastern part is clearly visible on the map. The southwestern part shows a series of strong, positive, roughly circular anomalies where the elongate shape of high magnetic anomalies in the north of central part is surrounded by the magnetic quit zone. The southeastern part shows an intensive magnetic anomaly zone oriented in a north-south trend. The western edge of this anomaly is marked by a sharp magnetic gradient.

Fig. 5.4(b) presents the result of RTP in the OASIS program contains the second inclination as in the Equation 2. The second inclination of Thailand presented by Tulyatid (1995) at 67° is applied. This map shows that the noises in north-south direction appeared particularly in the western part and central part. Many anomalies are more obvious than that in Fig.5.4 (a), especially in the northern part of the area. Moreover, the size of anomalies seems to be larger than the first map. However, this map still shows the negative anomalies and some areas shows the noise in an east-west direction.

Fig. 5.5 illustrates the RTP processing by using the OASIS program. It used several second inclinations similarly in equation 2. The second inclination (I_a) in Figs. 5.5 (a), (b), (c) and (d) are at 22°, 30°, 45°, and 60° N, respectively. To compare the result of the RTP in case of NS stretching, negative response, and suppressed amplitude (see black box in Fig 5.5), the map applying second inclination 30° (Fig.5.4 (b)) shows the more clear anomalies and less noise than the others. Nevertheless, there is still noise in north trending at ring feature in the central part. This illustrates that identification of the nature of the noise that contaminates real data is a difficult task. In addition, the details of anomalies of this map are obviously shown principally, in the western part of the area.

The negative anomalies are decreased and the anomalies in southern part are clear, as the dipole response of granite intrusions become monopole response.

Fig. 5.6 shows the RTP map using the ChrisDBF Program. The RTP operation using this program applies the same first inclination (22°), but the second inclinations are changed to 22°, 30°, 45° and 60°, respectively. From the results, if the second inclinations are increased, the negative magnetic intensities are amplified as the pair with the high magnetic intensities as shown in Figs. 5.6 (c) and (d). From these comparisons, the best of secondary inclination for this area is shown in Fig. 5.6 (b) and indicated $I' = 30^{\circ}$, same as above. It shows a clear anomaly and less noise in north-south direction compared with another inclinations (see black box in Fig 5.6). In addition, the RTP anomalies from ChrisDBF program seem to be processed with more detail preserved than the OASIS program. For example, in the western part, the elaboration of anomalies inside the large circular anomalies and at the ring pattern in the central part, the boundaries of small stock dykes are certainly restricted.

However, there is north-south noise only in the south edge of the map. The maps shows that the reduction to the pole maps contain mostly geological information, although some trending along the geomagnetic meridian is presented.

The reduction to the pole map, shown in Figs. 5.5(b) and 5.6(b), have been used to locate and interpret geological formations in this region. Other processing, such as first vertical derivative comes after the best RTP processing. The map illustrates the stability of the procedure, as less north-south effects are present. However, I have presented the comparison the reduction to the pole technique at low latitudes that the results are only from the fully automated programs. Furthermore, the RTP results are only used in the Loei area. In other areas, the RTP result should be tested for the best outcome.

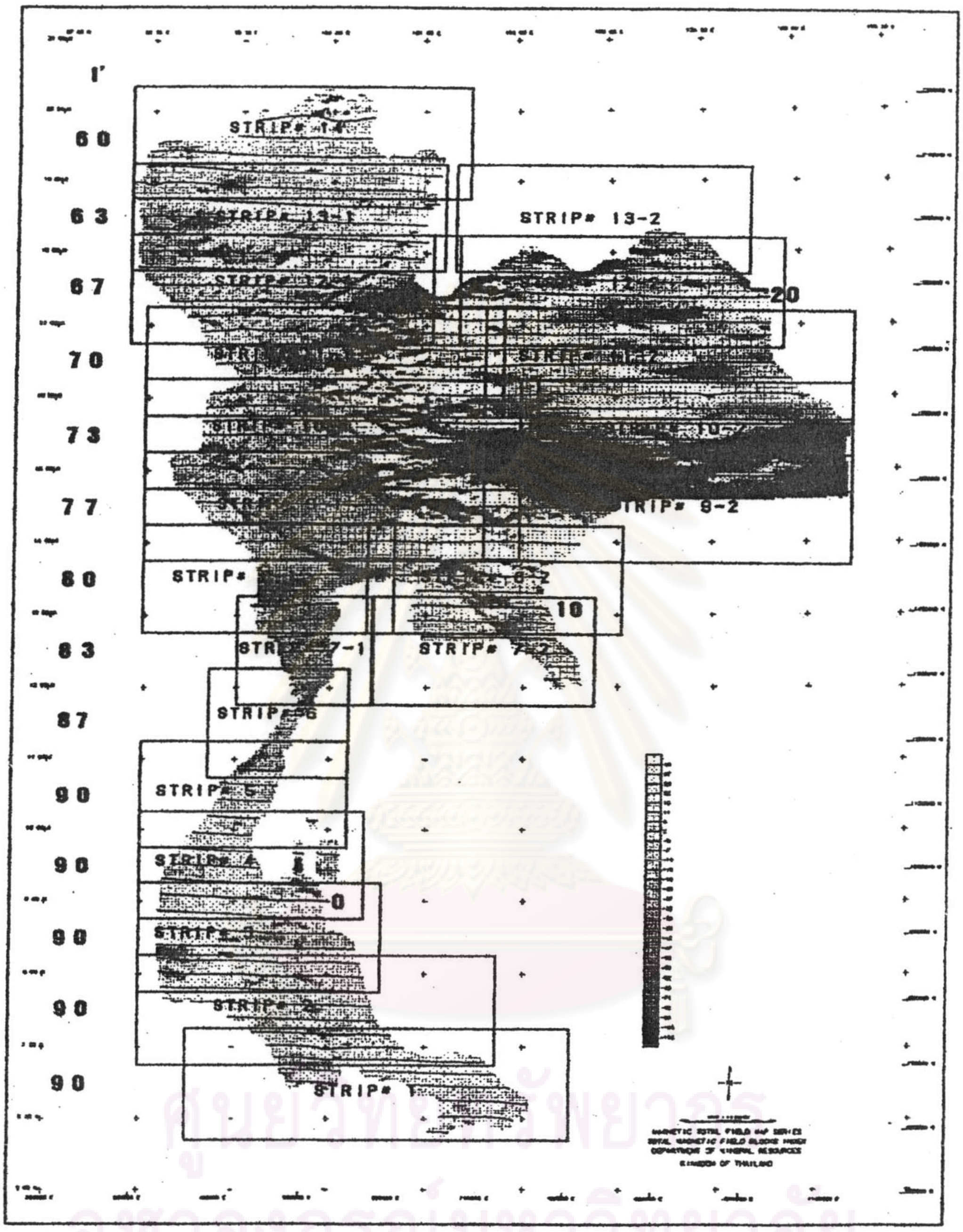


Figure 5.3 An index to the aeromagnetic data strips, magnetic inclination, and the suggest I' from Tulyatid (1995).

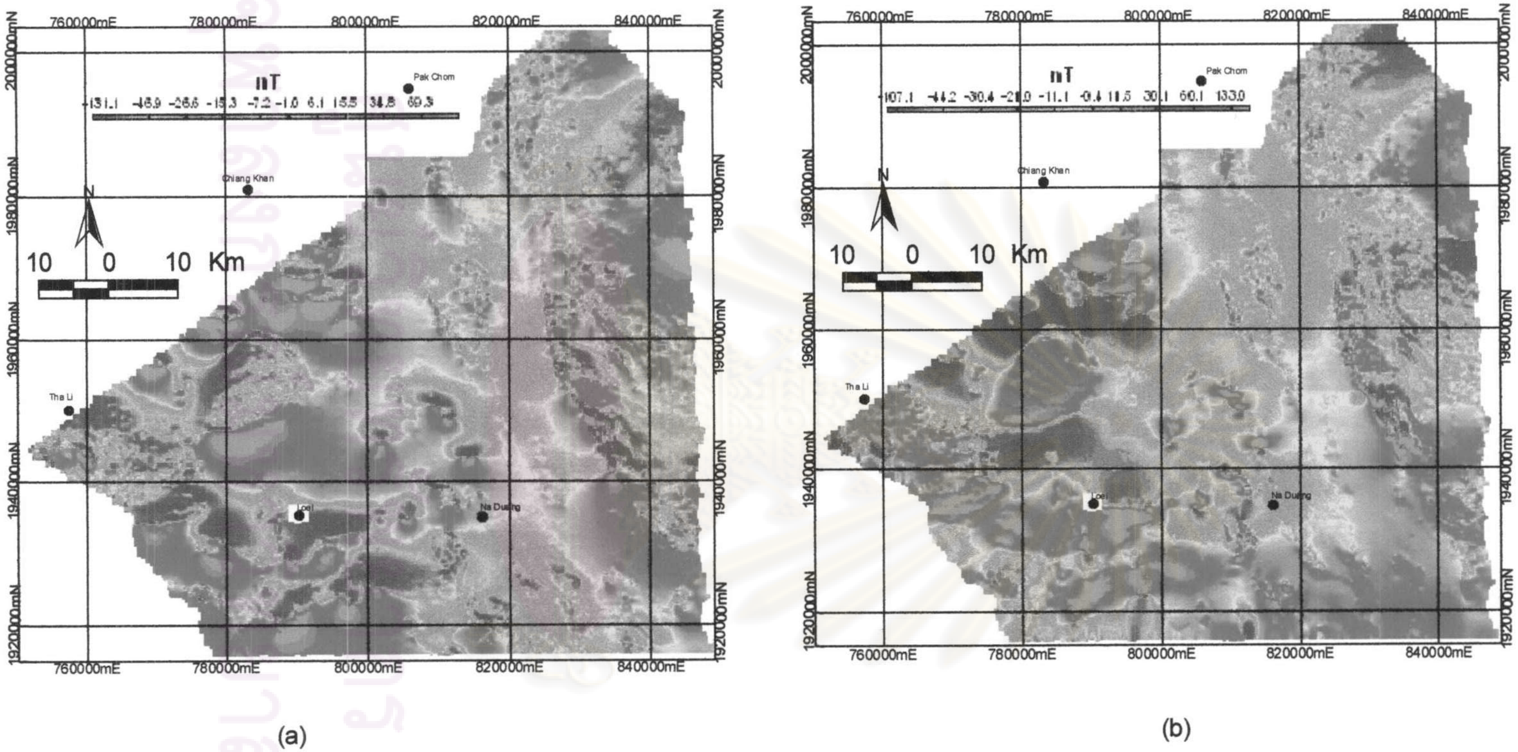


Figure 5.4 (a) The residual magnetic map of the Loei area, and (b) the reduction to the pole using the secondary inclination of 67°

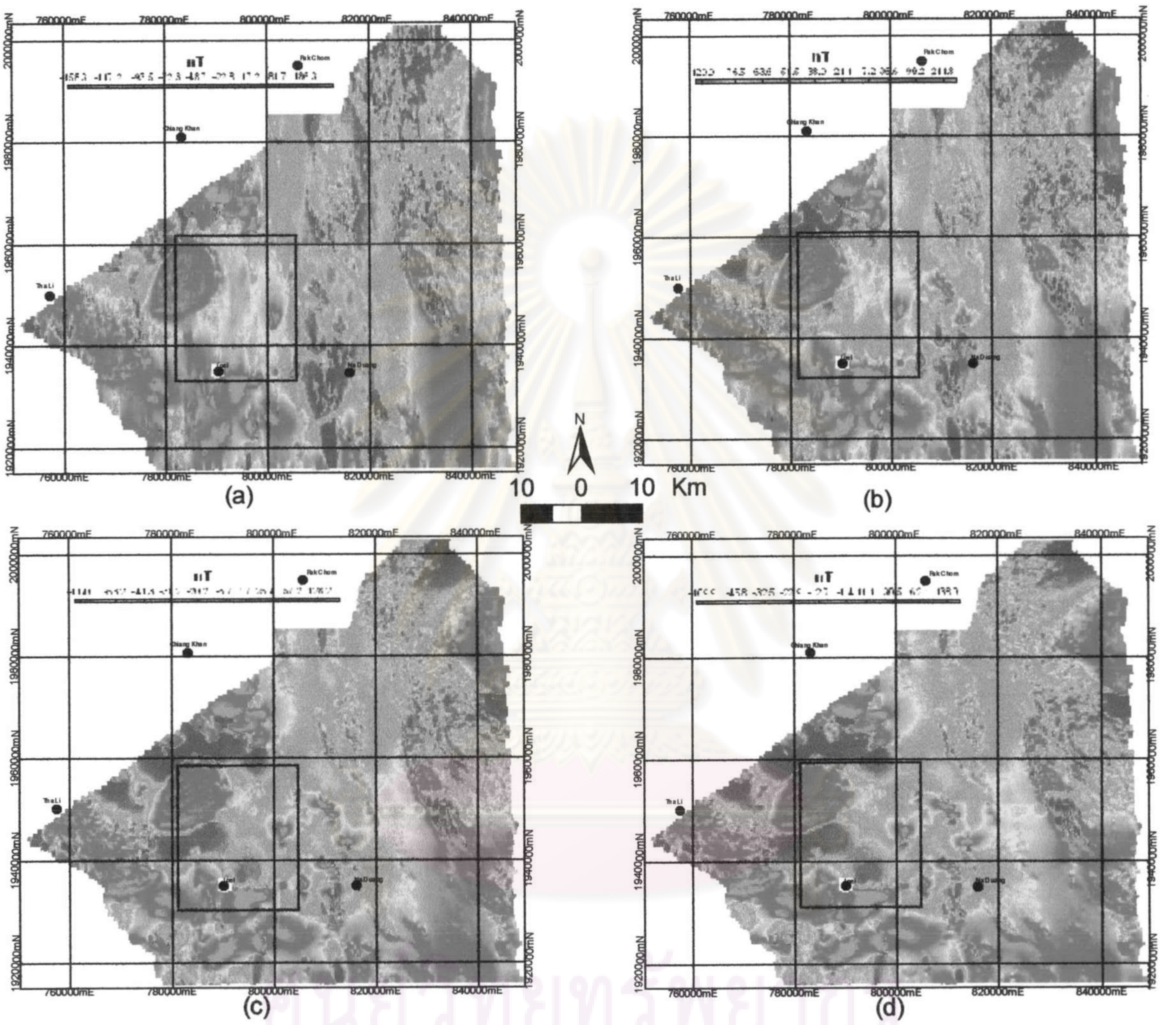


Figure 5.5 RTP map of the Loei area using the OASIS program by applying the different I' values of (a) 22°, (b) 30°, (c) 45°, and (d) 60°.

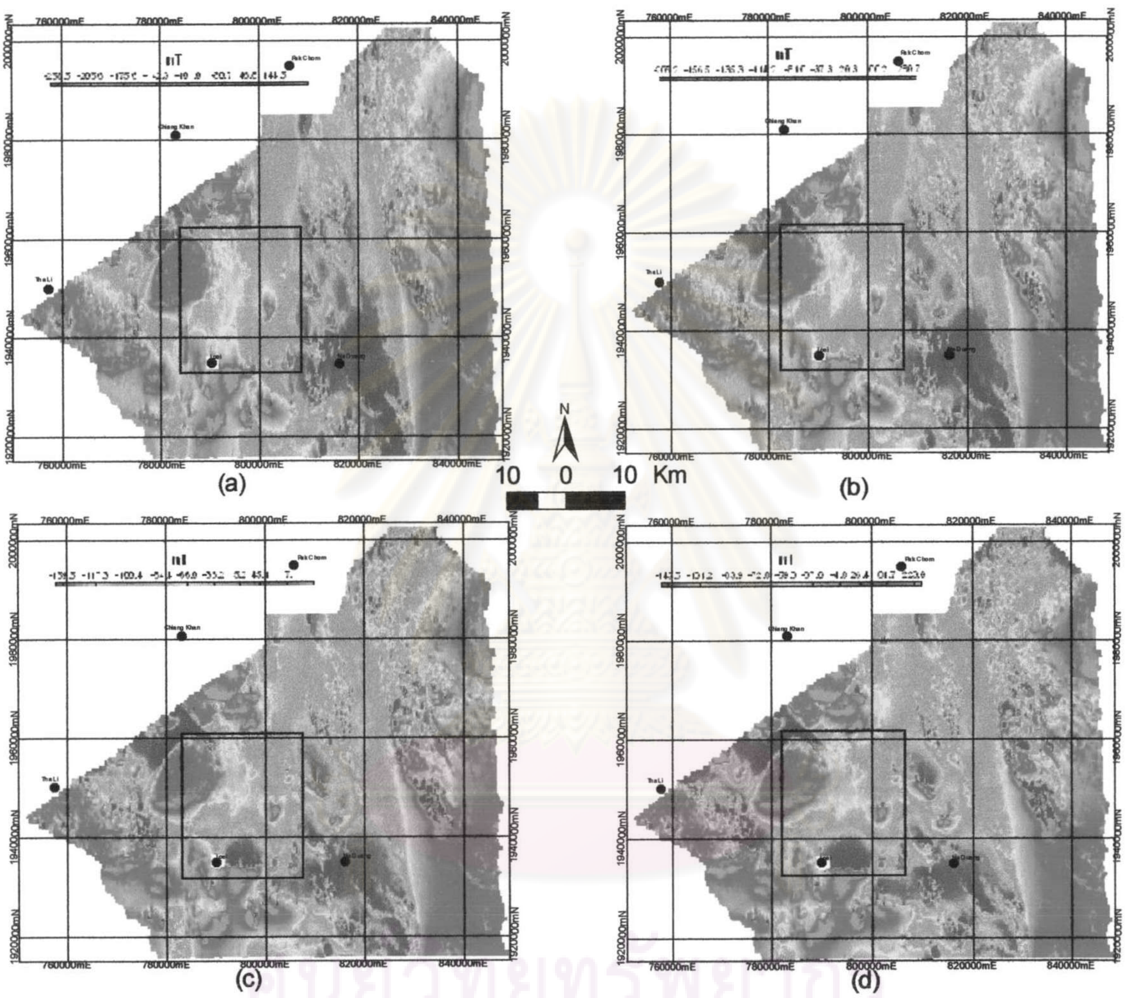


Figure 5.6 RTP map of the Loei area using the ChrisDBF program

by applying the different I' values of (a) 22°, (b) 30°, (c) 45°, and (d) 60°.