The error of projected total intensity anomalies and importance of the three component anomalies

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ABSTRACT

Magnetic surveys conducted for the purpose of mapping subsurface geological structures have been largely confined to measurements of the total intensity of geomagnetic field. Since the anomalous field caused by magnetized bodies is normally much smaller than the geomagnetic main field, it is assumed that the total intensity anomaly lies in the direction of the main geomagnetic field.

However, the direction of observed geomagnetic field is always different from that of the main geomagnetic field due to non-zero magnetic anomaly field. The magnetic anomaly field made by projection of the magnetic anomaly field on the geomagnetic main field is different from the total intensity anomaly. The difference between the projected anomaly and the total intensity anomaly, called projection anomaly error is obtained from three component anomaly fields, therefore the error estimation for the analysis results obtained so far using the total intensity anomalies could not be carried.

The relative projection anomaly error (projection anomaly error/total intensity anomaly) usually reaches a few %, however due to the combination of the main field and the magnetization, it reaches over a few of 10%. Then it can be said that for example, the magnetization calculated from the total intensity anomalies includes a significant error. The three component magnetic survey is required instead of the total intensity survey to overcome this kind of error.

1. Introduction

Until the invention of a proton precession magnetometer (PPT) (Packard and Varian 1954), the flux-gate type magnetometer had been used for the total intensity magnetic survey. Since the seafloor spreading theory was proposed (Dietz 1961, Hess 1962), PPT has been world-widely used for marine, land and aero magnetic surveys.

In the begging of 1960s, the methods for interpretation of total intensity anomalies to obtain the magnetization of arbitrary shaped underground body by many authors (e.g. Vaquier 1962, Bhatacharrya 1964, Talwani 1965). In all of these methods, the total intensity anomaly (TIA) was regarded as the projected total intensity anomaly (**PTA**) on the geomagnetic main field (**MF**) because **PTA** is the vector field which holds the physical quality leading the relation between **PTA** and the magnetization, while TIA is a scalar which could not hold any physical equations and relations. For example, Parker and Klitgord (1972) described clearly this situation (page 263) such

… It is convenient in upward continuation studies to work with harmonic functions (those obeying Laplace's equation), but the measurements are of the total field |**TF**|, which is not harmonic. …

In 1970s, many studies of the spherical harmonic coefficients(SHC) concerning the International Geomagnetic Reference(IGRF) model showed the many aspects of disadvantages in SHC using TIA , for instance, inherent vector discrepancies (Hurwitz and Knapp 1974), error enhancement (Stern and Bredekamp 1975) , non-uniqueness (Backaus 1970) and so on. Hurwitz and Knapp (1970) showed that the geomagnetic main field model obtained from TIA produced the discrepancies between observed and simulated vector fields and proposed complete vector measurement for HSC analysis. And they pointed the ΔTF perpendicular effect (TF ; the geomagnetic total intensity, the detailed in the later section) which imparts the resulting error in the output model.

The only way to avoid the problem mentioned above on TIA due to the error, ε_T (=TIA-|**PTA**|;see the detailed in the later chapter) , is to use the vector magnetic field instead of TIA. The vector magnetic surveys have been carried out since Shipboard Three Component Magnetometer (STCM) and Deep Tow Three Component Magnetometer (DTCM) were developed (e.g. Yamamoto et al.,2005). The vector magnetic anomalies can provide the information on many aspects of magnetization, for instance, the top depth and the dip angle of 2D magnetization source (Nabighian, 1972), and the direction of magnetic anomaly lineations from only one profile (Isezaki, 1986). Kato et al. (2007) used these methods for the vector anomaly lineations in the Japan Sea.

In this study, we will show the estimation of the projection anomaly error, ε_T in analysis results using TIA. The bold letters for magnetic fields represent the vector quality and normal letters the scalar one throughout the paper.

2. Perpendicular effect

Many studies about the underground magnetization structure have been conducted so far. In every case, the data used for analyses were TIA defined as the intensity difference between **TF** (the total intensity of observed geomagnetic field) and **MF** (the geomagnetic main field), namely,

$$\mathrm{TIA}=|\mathbf{TF}| - |\mathbf{MF}| \qquad (1)$$

Because TIA is a scalar without information of its direction, TIA is not a harmonic potential field and does not hold Laplace's equation. Usually **MF** is defined from the international geomagnetic main field model.

TA (geomagnetic anomaly field) is defined as

$$\mathbf{TA} = \mathbf{TF} - \mathbf{MF} \qquad (2)$$

It is clear that TIA $\neq |\mathbf{TA}|$ except for the case that **TF** is parallel to **MF**.

PTA, the intensity of **PTA** is defined as

$$\mathrm{PTA} = \mathbf{TA} \cdot \mathbf{t} \qquad (3)$$

where **t** is the unit vector in the direction of **MF**.

The projection anomaly error, ε_T, the difference between TIA and PTA is,

$$\varepsilon_T = \mathrm{TIA} - \mathrm{PTA} = 2 \cdot |\mathbf{MF}| \cdot \sin^2(\beta/2) \quad \text{for TIA} > 0$$
$$= 2 \cdot |\mathbf{TF}| \cdot \sin^2(\beta/2) \quad \text{for TIA} < 0 \qquad (4)$$

where β is ∠BAC in Fig.1 below.

α

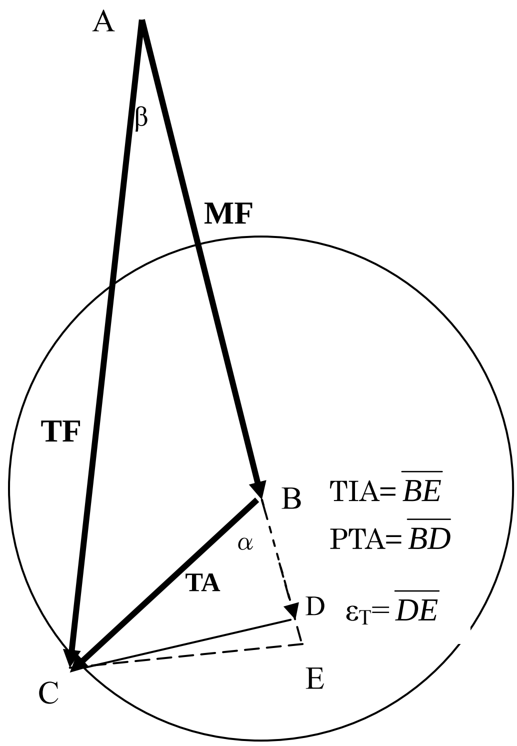

Fig.1 Geometrical expression for ε_T.

MF,**TF**,**TA,** and **PTA** are the vectors of geomagnetic main field, total field ,anomaly field and projected anomaly field respectedly. **MF**= $\vec{AB}$,**TF**= $\vec{AC}$, **TA**= $\vec{BC}$,**PTA**= $\vec{BD}$,TIA= $\overline{BE}$, PTA= $\overline{BD}$ and ε_T= $\overline{DE}$. $\overline{AE} = \overline{AC}$, $\overline{CD} \perp \overline{BE}$, and β=∠BAC, and α=∠CBD.

Fig.1 shows the geometrical relations of magnetic components on the plane where **MF**,**TF** and **TA** coexist. If β is so small, then ε_T is so small (see Equation (4)), namely **TF** is regarded to be parallel to **MF**, TIA is almost the same as PTA. Then TIA has been regarded as the one component of magnetic anomaly field in the direction of **MF**. Because **PTA** is one component of the geomagnetic potential field, **PTA** is harmonic and holds Laplace's equation while TIA does not, and **PTA** can be defined using the scalar magnetic potential v, thus

$$\mathrm{PTA} = -\frac{\partial v}{\partial t}$$

$$\nabla^2 PTA = \nabla^2 (-\frac{\partial \nu}{\partial t}) = -\frac{\partial}{\partial t}(\nabla^2 \nu) = 0 \qquad (5)$$

where t indicates the direction of unit vector of **MF**.

As seen in Fig.1, β and ε_T reach the maximum when **TF** is the tangent vector on the circle of Fig.1 where **TA** is almost perpendicular to **MF** (α≈pi/2), because |**TA**| is generally much smaller than |**MA**|, namely **TF**≈**MF** (TIA≈0). In the practical case, there is no information for **TA** in the |**TF**| survey, **TA** must be assumed for estimation of ε_T. When MF and TA are assumed as MF=50,000nT and TA=1,000nT, ε_T is obtained from equation (4) at any β and α. Fig.2 shows the relative projection anomaly error defined by ε_T/TIA for TIA from 1,000nT to –1,000nT. β changes from 0 at TIA=$\pm 1{,}000nT$ to the maximum (≈TA/MF=0.02) where **TA** is almost perpendicular to **MF** and TIA≈0nT while α changes from 0 to pi. **TF** is produced by adding vector **TA** to vector **MF** as β changes from 0 (radian) to the maximum (about 0.02 radians). **MF**, **TF** and **TA** are assumed to be always on the same plane, and then this model corresponds to 2D model. The abscissa, β in this case, correspond to either distance or time in the actual case.

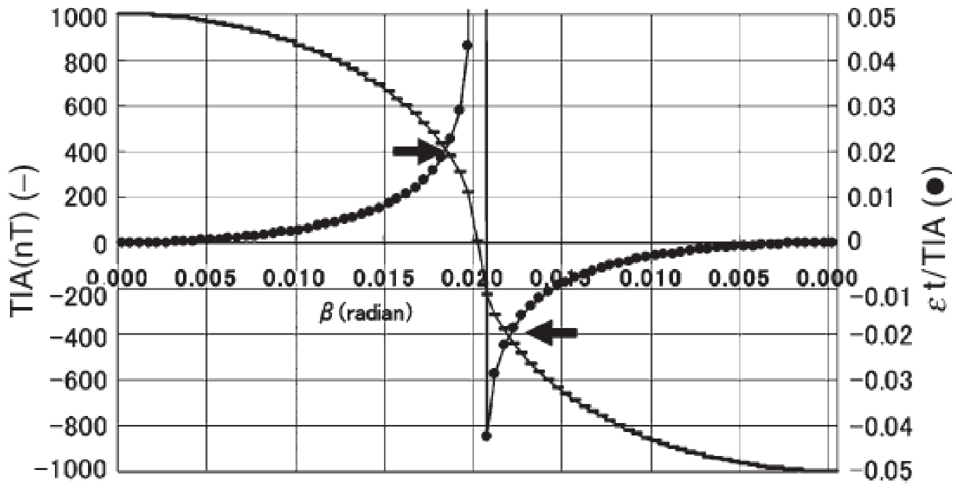

Fig. 2. Relation between TIA and e_T/TIA

TA rotates around the point B in Fig.1. While α increases from 0 to around 90 degrees, β changes from 0 to 0.02 radians, with TIA decreasing from 1000 to 0nT. When **TA** rotates more (90° > α > 180°) in the same plane, β changes from 0.02 to 0 radians as TIA decreases from 0 to −1000nT. The two arrows indicate that e_T/TIA =±0.02 corresponds to TIA =±400nT.

In the example shown in Fig.2, the prominent feature that the relative projection error e_T/TIA increases very rapidly to the almost infinite value at around β=0.02(α=pi/2) is called the ΔTF perpendicular effect. e_T/TIA is greater than 0.02 (2%) for |TIA| > 400nT, which may mean that the result of magnetization analysis in which the magnetic anomaly fields are related linearly to magnetization will be affected by at most 2% by using |TIA| < 400nT and 5% by using |TIA| <200nT. When e_T/TIA=1(100%), the number of significant digits of analysis result is 0, and when e_T/TIA=0.01(1%), the number of significant digits is 2. Then for e_T/TIA=0.02(2%), the number of significant digits will be 1.7, and for e_T/TIA=0.05(5%), it will be 1.3. If TA = 500nT is adopted, e_T/TIA=0.02(2%) for |TIA| < 120nT.

3. 3D spaced 3 component magnetic survey

Though it is very difficult to know how the relative projection anomaly error e_T/TIA influences the analysis result, it is useful to see the inversion result for magnetization analysis for a 3D block model in Fig.3, which shows that TIA does not provide a good inversion solution, whereas **PTA** and three-component anomalies can provide an almost-exact inversion solution. It is very clear from Fig.3 that it is difficult to estimate how much accuracy (or error) the solution obtained from an actual observed TIA might have.

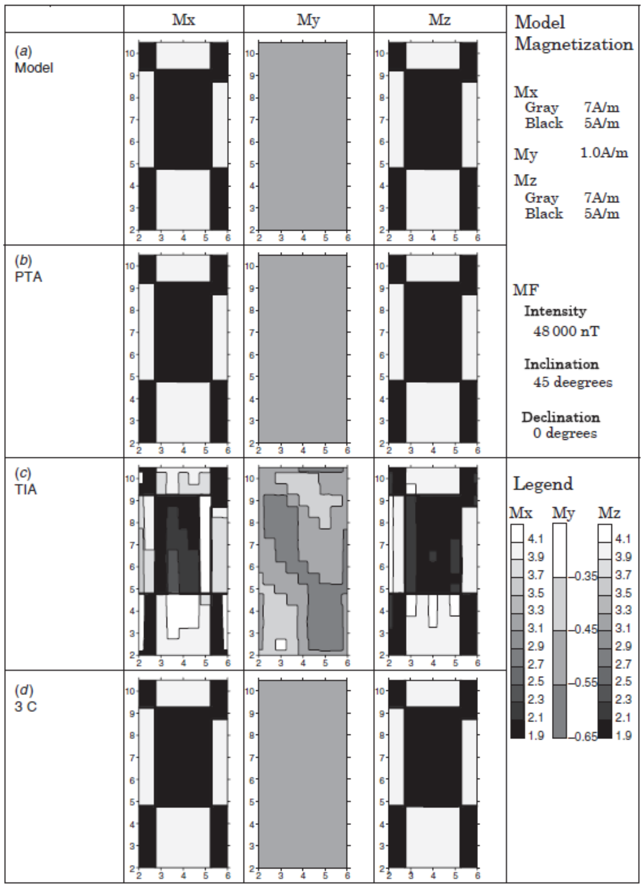

Fig. 3. Inversion results for three components of magnetization

(a) Model; (b) Inversion result using **PTA** as the input data; (c) Inversion result using TIA; (d) Inversion result using three-component anomalies. The magnetization model was a flat plate made up of an aggregation by blocks. The thickness of the plate was 2000 m; the length and width of each block was 500 m. The total number of prismatic blocks was 162 (18 north,9 east), and as each block had three components of magnetization, then there were 486 unknowns. Magnetic anomaly data on planes 200, 350, 450, 500, and 550m above the surface of the plate were used. The total number of observed (calculated) data was 6377. To calculate TIA and PTA, the following parameters were assumed for **MF**. 1) |MF| = 48 000 nT; 2) The declination was 0 degrees; 3) The inclination was 45 degrees.

We conducted the 3D spaced 3 component magnetic survey over Aogashima Island on December 6, 2006. The survey was flown with Global Positioning System (GPS) control, at mean altitudes of 100, 300, and 600m along north–south flight lines spaced 300m apart.

Then we can determine the reliable magnetization distribution in Aogashima volcano body and make sure the points for the advantage of 3 component anomalies for magnetization analysis mentioned above.

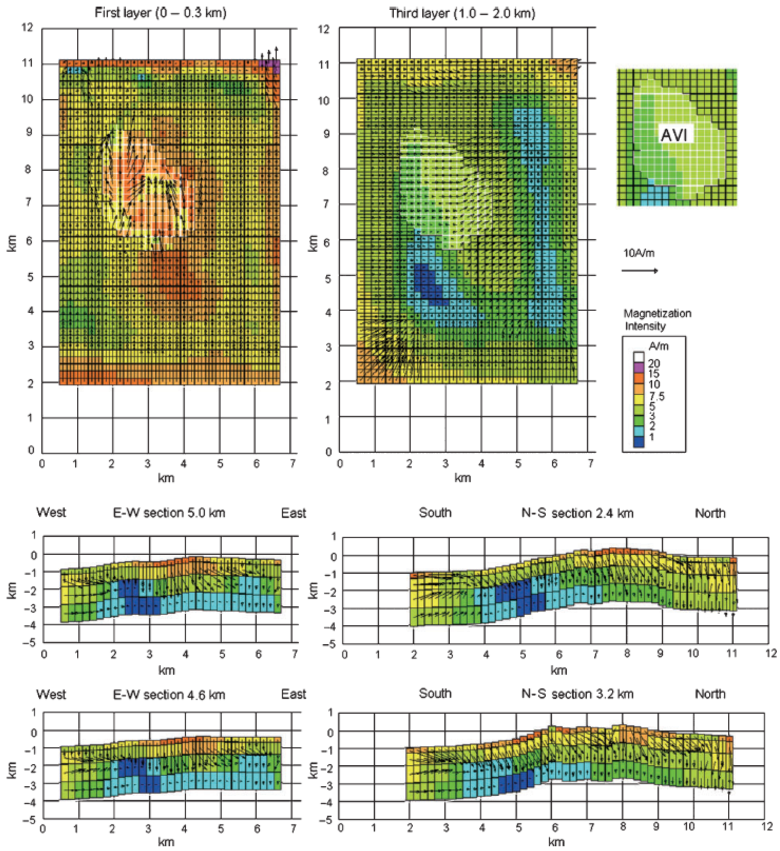

Fig. 4. Distribution of magnetization intensity and magnetization direction.

The Aogashima Volcanic Island(AVI) was assumed to be composed of 4 layers. The number of blocks in each layer was 1426, therefore, our model was composed of 5704 (46 north,31 east,4 layers) blocks. Because each block has three components of magnetization to be determined, the total number of unknown parameters was 17,112 (46x31x4x3). To calculate these parameters, 20,766 three-component magnetic anomaly data observations were used.

The detailed interpretation of Fig.4 will be appeared in the paper by Matsuo et al. in this proceeding.

4. Conclusion

The TIA has an intrinsic error that cannot be avoided, even by a high-resolution magnetometer. Moreover, examination of model analyses shows that an inversion result using TIA may be very different from the true model, while the vector anomaly does provide an inversion result almost identical to the true one. To avoid this error, the 3 component (vector) magnetic anomalies should be used instead of TIA.

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