

Correlation between the Relief and the Magnetic Field in Kuju Volcanic Area

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ABSTRACT

Two approaches for establishing the relationship between the topography and the magnetic field in Kuju area were applied. The first one includes transformation of the measured magnetic field ΔT to the field of the modulus T of the anomalous magnetic intensity \mathbf{T} . The second one is based on modeling of the magnetic topography and correlation of the modeled anomaly with the measured anomalous magnetic field ΔT . The T transform map shows high values over the domes of Naka-dake and Mimata-yama and not so intensive magnetic anomaly over Hossho-zan. The comparison between the observed and the modeled field shows a generally high correlation between the topography and the magnetic field in Kuju area, with noticeable lack of correlation around Hossho-zan and the new crater zone of the fumarolic area of Kuju-Iwoyama. The areas of low correlation may be related to demagnetisation by the heat of the magma chamber or hydrothermal alteration by hot ground water.

1. Introduction

In volcanic areas magnetic modeling of the terrain can provide useful information about demagnetisation of parts of the topography by the heat of the magma chamber or hydrothermal alteration by ground water.

Kuju volcano is situated in the western part of the Hohi volcanic area, occupying the eastern part of Beppu-Shimabara graben. The basement consists of Cretaceous granitic and metamorphic rocks overlain by Pliocene to Middle Pleistocene andesitic rocks. The surface geology around Kuju volcano is mainly represented by Late Pleistocene hornblende andesitic rocks, partly by dacitic material to the west of Mimata-yama, and in the lower parts to the east of Mimata-yama by sand and gravel.

Kuju area has been covered by an aeromagnetic survey as a part of a combined magnetic and electromagnetic study in March 1996, following the 1995 eruption of the volcano, at ground clearance between 10 m and 90 m (Dowa Koei Co., 1996). The survey was conducted along N-S trending flight lines with 200 m and 400 m spacing between the adjacent lines. The area around Hossho-zan was flown in more detail at spacing 100 m. Thus, the data in the vicinity of

the active fumarolic area is more representative. The measured magnetic field in the area varied between 46340 nT and 48900 nT. The anomalous magnetic field with removed IGRF is shown in Figure 1. The field is characterised by intensive anomalies with normal pattern over Mimata-yama and Naka-dake, with positive extrema of 2467 nT and 2211 nT, respectively. The volcanic rocks of Hossho-zan create a positive magnetic anomaly of 625 nT. The four fumarolic zones (A, B, C, D) are denoted with dotted areas. The dashed line represents the contours of the alteration zone (Kohmatsu and Taguchi, 2001).

2. Methods and results

2.1 Transform T

The first approach to find whether a relationship between the relief in Kuju area and the magnetic field exists is the calculation of a transformation of the measured field that has a pattern similar to the shapes of the sources causing the field and anomalies well centred over these sources. Such a transformation is the modulus T of the total anomalous magnetic vector \mathbf{T} , calculated using the formula $T = (X^2 + Y^2 + Z^2)^{1/2}$, where X , Y and Z are the components of the magnetic field in North, East and vertically down direction.

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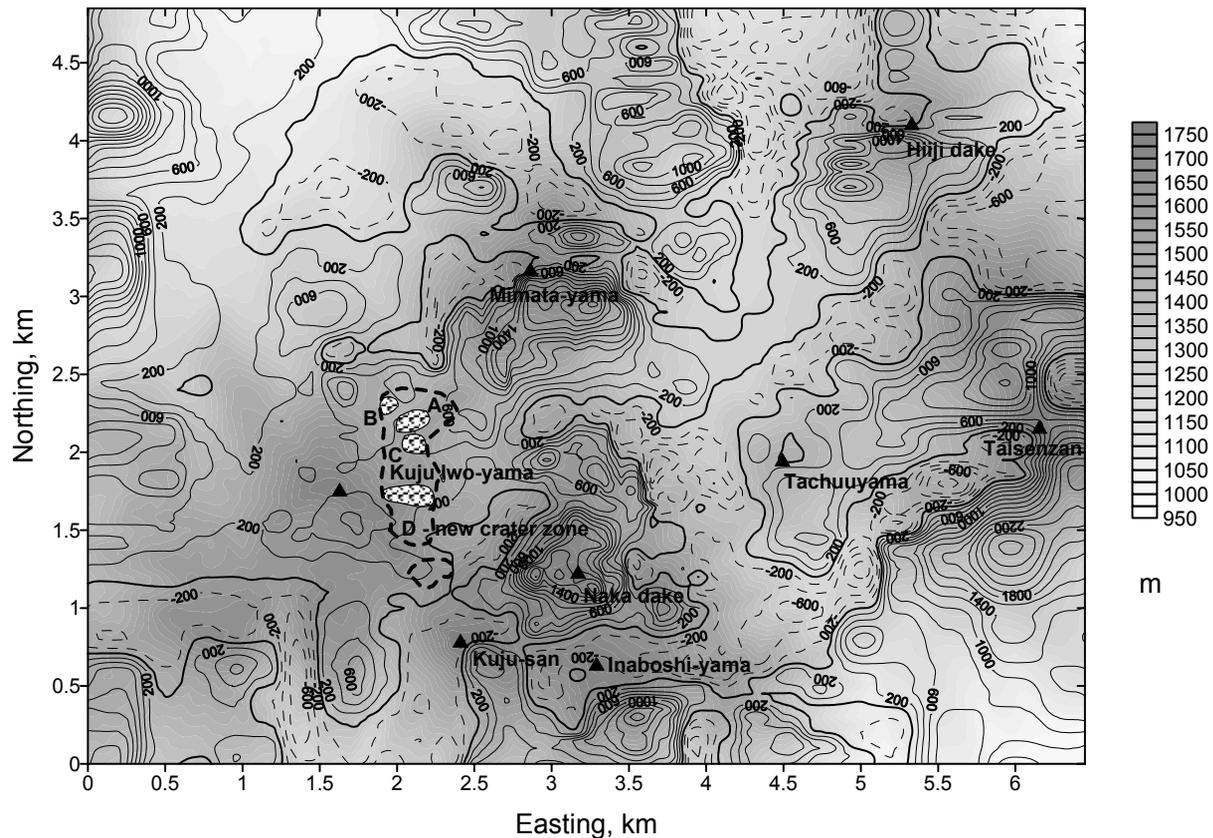


Figure 1. Contour map of the observed total anomalous magnetic field ΔT , nT, overlaying the image map of the topography.

It is a transform of the same order as the measured anomalous field ΔT (Stavrev and Gerovska, 2000). The transformation of the measured anomalous magnetic field ΔT to the modulus of the total anomalous vector \mathbf{T} possesses the properties to be low dependent on the direction of the vector of source magnetisation and to be well centred over the magnetic sources. Compared to the measured field ΔT , transform T shows 10 times lower dependence on the magnetisation vector direction and considerably higher centricity. It has only non-negative values, which makes it easy to compare its anomalies directly with the topography.

The map of the calculated magnetic transform T can be seen in Figure 2. It shows high values over the domes of Naka-dake and Mimata-yama, with maximums 3760 nT and 4300 nT, respectively. Considerably smaller are the values over Hossho-zan of the range of 1090 nT. It should be noted that the respective heights of the three peaks are close and that the three domes have comparable amount of volcanic material above sea level. The pattern of the T transform map is similar to that of the Reduced to the pole field (Dowa Koei Co., 1996), which confirms that the sources of the magnetic field have magnetisation vector direction close to that of the present Earth's

magnetic field.

The depth interpretation of the radially averaged spectrum of the measured magnetic field with the method of Spector and Grant (1970) (Figure 4.a) shows that the deepest group of sources has an average depth to the top 187 m which suggests that the main source of the magnetic field are the volcanic rocks close to the surface.

2. 2 Magnetic modeling of the terrain

Another approach for determining the possible correlation between the relief and the magnetic field is the modeling of the magnetic topography and the compilation of a map of the correlation coefficients of the modeled and the measured magnetic fields. Two modeling methods have been applied. The first one was implemented in the space domain and the second one in the frequency domain.

The modeling of the magnetic relief in the space domain was implemented by representing the topography with vertical homogeneously magnetized prisms at every point of the topographic grid with distance between the grid points 0.05 km in North and East direction. A topographic map of scale 1:25,000 has been used. A radius of 0.4 km was chosen to

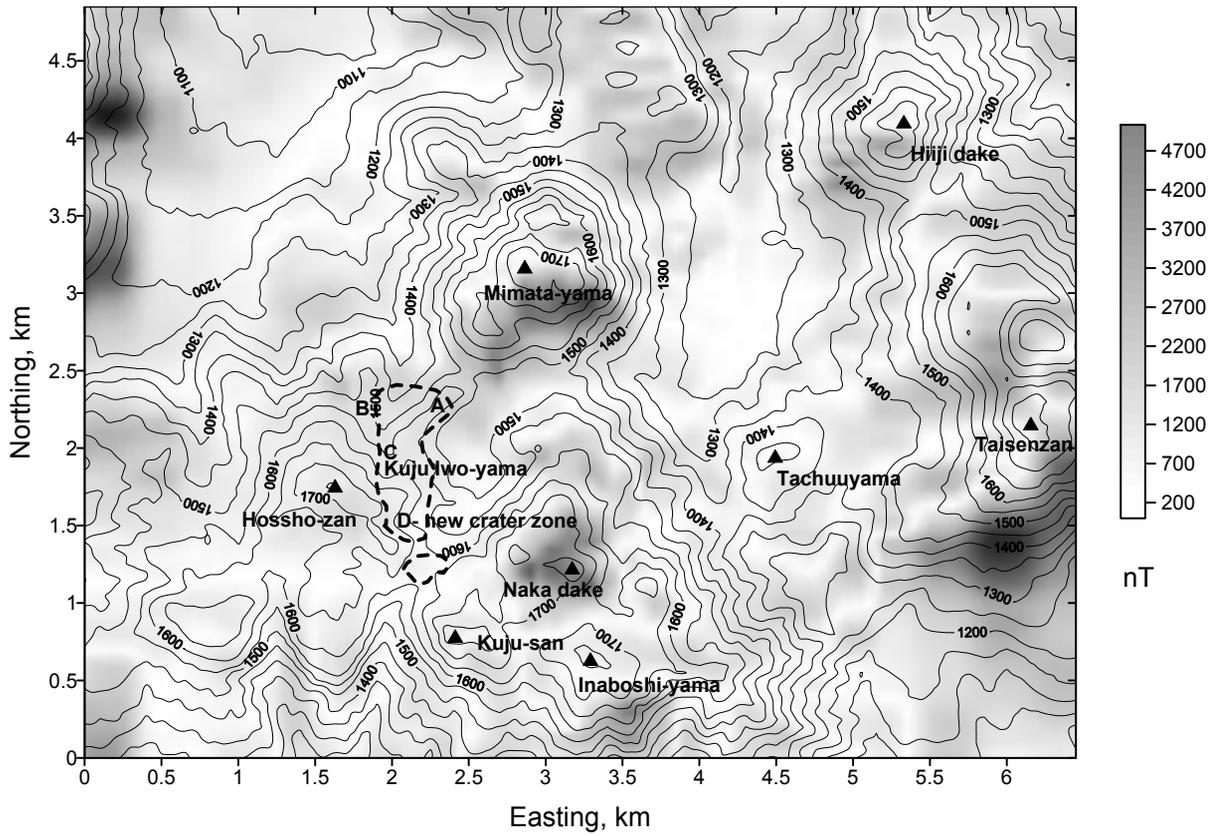


Figure 2. Image map of transform T , nT, overlain by the contour map of the topography. The contour interval of the topography map is 50 m.

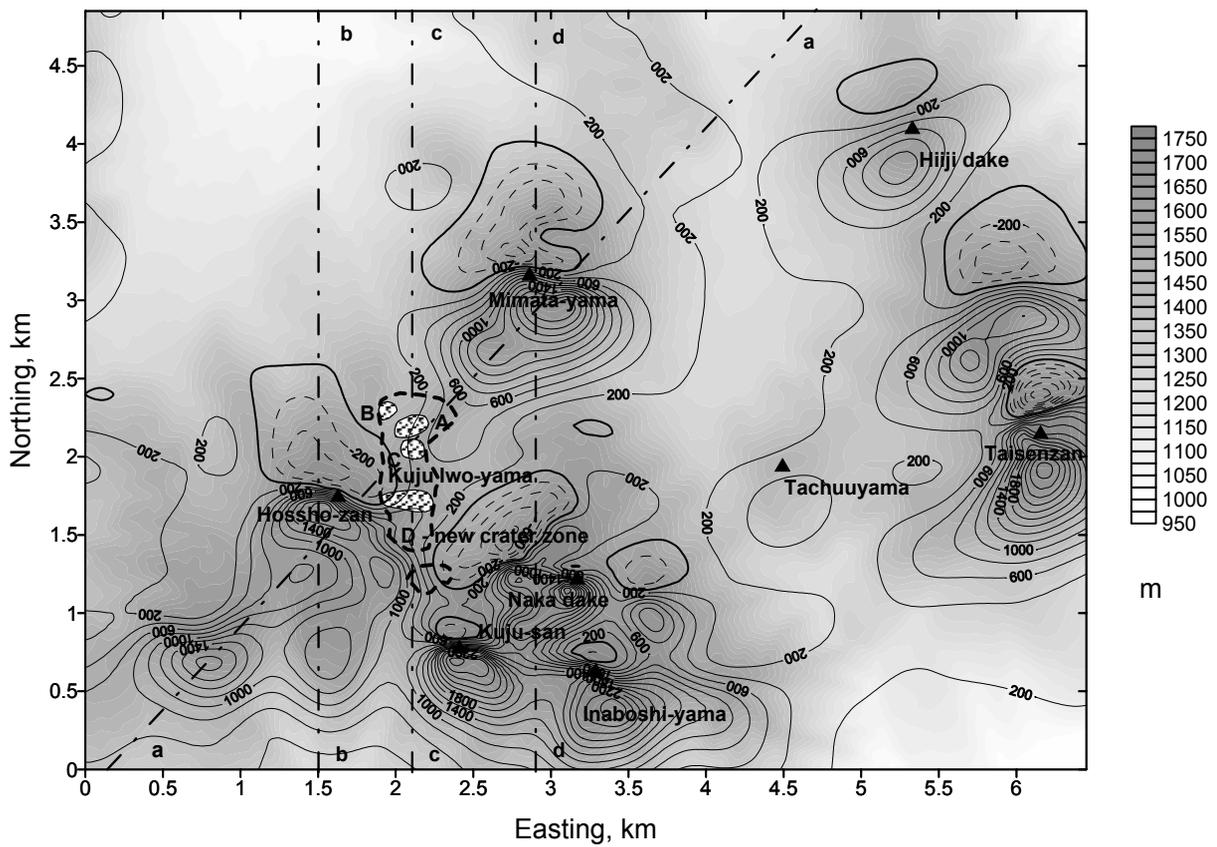


Figure 3. Contour map of the model of the magnetic topography, ΔT , nT, calculated with the prism model, underlain by the image topography map.

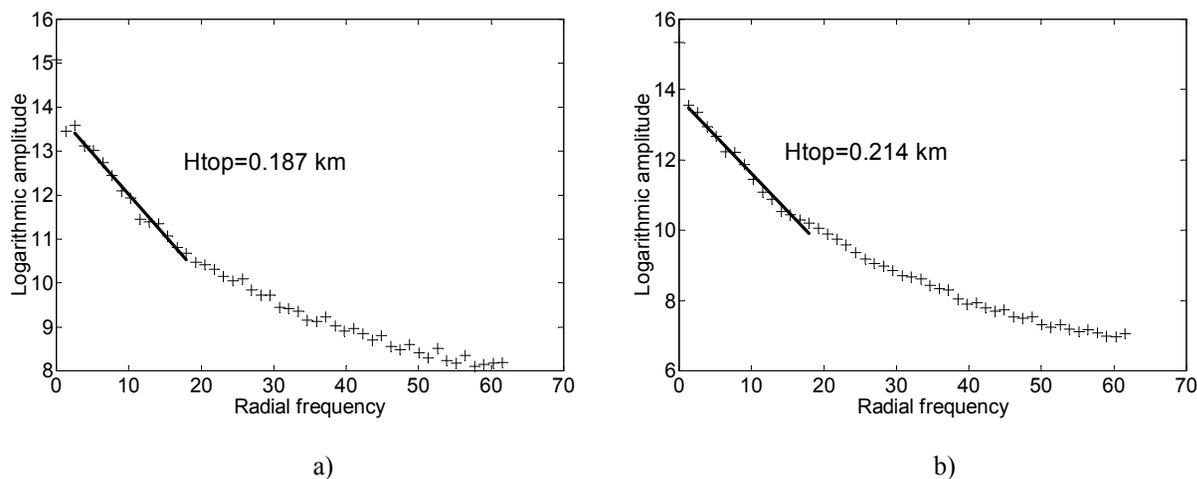


Figure 4. Logarithmic amplitude spectrum: a) The measured anomalous magnetic field ΔT ; b) The calculated magnetic field ΔT with the uniform magnetisation prism model.

approximate the magnetic field of the topography, which means that only the influence of the prisms within an area of this radius was considered. In order to match the intensity of the observed anomalous magnetic field, the intensity of magnetisation was chosen to be 7.7 A/m and the value was determined by dividing the standard deviation of the observed

field by the standard deviation of the calculated field of the terrain with unit magnetisation. The direction of magnetisation was chosen to be the direction of the ambient magnetic field, which has declination -6° and inclination 47° . It was also assumed that the model had a flat bottom at sea level. The calculation level was set at 1.82 km a.s.l., which is 40 m above

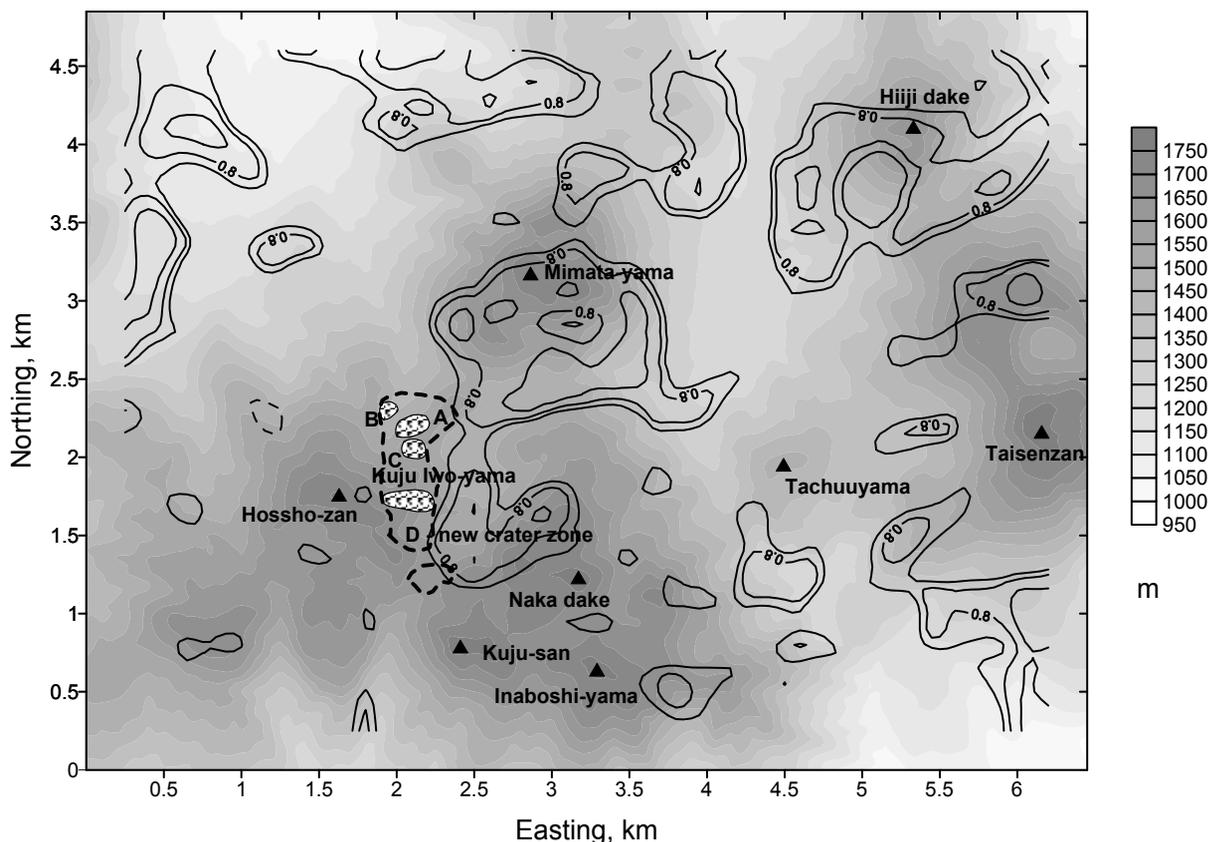


Figure 5. Contour map of the spatial correlation coefficients between the measured and the calculated with the prism method modeled magnetic field ΔT , overlaying the map of the topography.

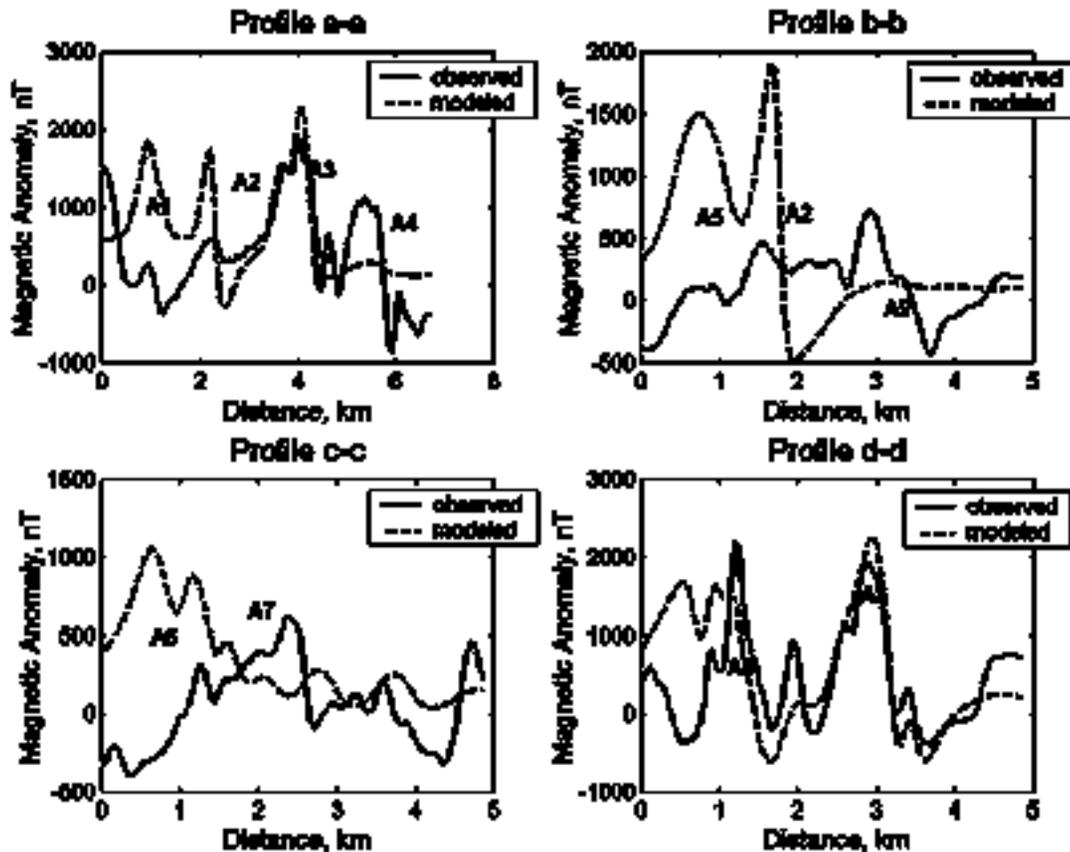


Figure 6. Profiles extracted from the observed and modeled with the prism method field maps. The location of the profiles is shown in Figure 3.

the highest terrain point in the area. The Spector and Grant interpretation of the modeled field (Figure 3) gives an average depth of 214 m (Figure 4.b), which is in agreement with the result obtained from the interpretation of the measured field, 187 m (Figure 4.a) and proves the good quality of the model.

The modeled magnetic field was compared to the map of the topography and as a result the correlation map shown in Figure 5 was compiled. The latter shows high positive correlation coefficients of the order 0.9 around Mimata-yama and Naka-dake, which suggests that the volcanic rocks of these domes have preserved their high magnetic properties from the time of their formation. This is typical for Quaternary volcanic rocks. The active area of Kuju-Iwoyama, as well as the area over Hossho-zan, does not show such correlation, which was initially expected. The low correlation in the active fumarolic area can be explained with geothermal demagnetisation. A confirmation is the established presence of an argillic alteration zone (Kohmatsu and Taguchi, 2001).

The comparison between the fields in Figure 1 and Figure 3 has been shown along several profiles (Figure 6). The location of the profiles is marked in

Figure 3. The sections of interest along the profiles are denoted with A, followed by the number of the section. Profiles a-a and d-d (A3) crossing Mimata-yama illustrate the fact that the magnetic rocks of the dome have preserved their high magnetic properties. The same could be noted for the Naka-dake lava (profile d-d, section A8). But the lava of Hossho-zan (profiles a-a and b-b, section A2) shows weaker magnetic properties, which suggests of alteration of the rocks in depth. The supposed alteration is not revealed as a surface alteration zone. Profiles a-a and b-b show lower values of the modeled sections A4 and A9 compared to the measured field but the discrepancy is most probably due to the fact that the model is calculated at a constant height of 1.82 m and the field is measured at ground clearance. Above the active fumarolic areas (profile c-c, section A7), the observed field is less intensive than the modeled in the southern new crater zone, and more intensive in the northern zone. The less intensive observed field to the south is in conformity with the active state of the area during the time of the survey. The more intensive one to the north could be a result of some small subsurface highly magnetic sources.

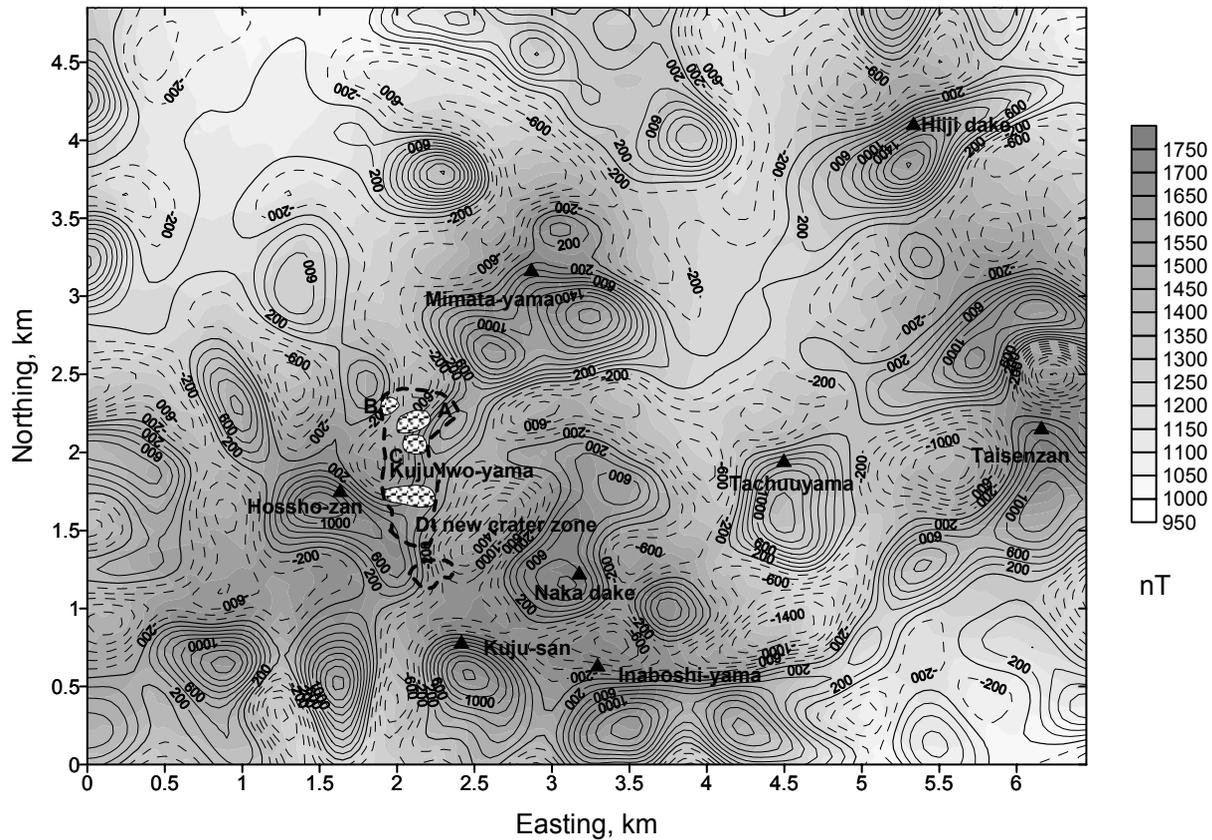


Figure 7. Contour map of the model of the magnetic topography, ΔT , nT, calculated with the Parker method, overlain by the image topography map.

The topography was modeled also with the fast Fourier method of Parker (1972), representing the spectrum of the magnetic field of the topography as a series of the spectrums of the heights of the topography in the respective grid points. The obtained result is similar to that obtained by the terrain modeling with prisms (see Figure 7).

3. Conclusions

The comparison between the T transform and the topography, as well as between the observed and the modeled magnetic field with the two methods in space and frequency domain, show that the magnetic anomalies in Kuju area are caused mainly by the volcanic rocks, constituting the topography. The high correlation indicates that the rocks of the lava domes of Mimata-yama and Naka-dake have preserved their high magnetic properties. It shows also that their rocks have not been altered by weathering or geothermal events. Different, lower magnetic properties, are shown by the volcanic rocks of Hossho-zan, which cause magnetic anomalies of lower intensity, compared to those of the equally high Mimata-yama and Naka-dake. One possible reason for the low cor-

relation between the relief and the magnetic field in Hossho-zan could be demagnetisation by the heat of located underneath magnetic chamber or hydrothermal alteration by hot ground water. Another possibility could be the difference in the chemical composition and in the respective magnetic properties of the andesitic lava, constituting Naka-dake and Mimata-yama. The low correlation in the new crater zone D is well reasoned by the active state of the area.

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