Subsurface structure of the Unzen graben based on aeromagnetic and volcanological data.

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Abstract

Aeromagnetic analyses have been conducted in and around Unzen Volcano, Kyushu, Japan, in order to reveal the subsurface structure of the Unzen graben. Finally, also from a viewpoint of magnetization structure as pointed out by the result of other geophysical data, it turns out that the Unzen graben has the feature of half-graben, which northern fault fallen in the western Unzen region and southern fault fallen in the eastern Unzen region, moreover, it clarified that magnetization lows (expand from east to west) corresponding to the hydrothermal alteration exists in the center part in the graben.

1. Introduction

Unzen volcano (Fig. 1) has been formed in the Unzen graben in a N-S extensional tectonic stress field. This volcano is cut by EW-trending normal faults, such as Chijiwa-, Kanahama-, Futsu- and Fukae-faults. Although these E-W trending normal faults run in the middle of the Shimabara Peninsula, the northern and southern boundaries of the graben are not clear because volcanic rocks have almost entirely filled the depression.

In this study, we aim to clarify a magnetic structure of the Unzen graben which progressed with volcanic activity and has been related closely, and to discuss the tectonic and geothermal subsurface structure based on these results. First, we reanalyzed the aeromagnetic data of August, 1991 (Nakatsuka, 1994) in order to clarify the regional spatial distribution of geology in the central part of the Shimabara peninsula. Next, we give new knowledge for main faults forming the Unzen graben by using low-altitude aeromagnetic data of 2002. These data allow us to identify the extent of individual geologic units, dislocations of faults, and the distribution of hydrothermally altered areas. Finally, we reveal 2.5-dimentional models for 3-dimensional interpretation and and discuss about these results based on other geophysical and drilling data accumulated so far

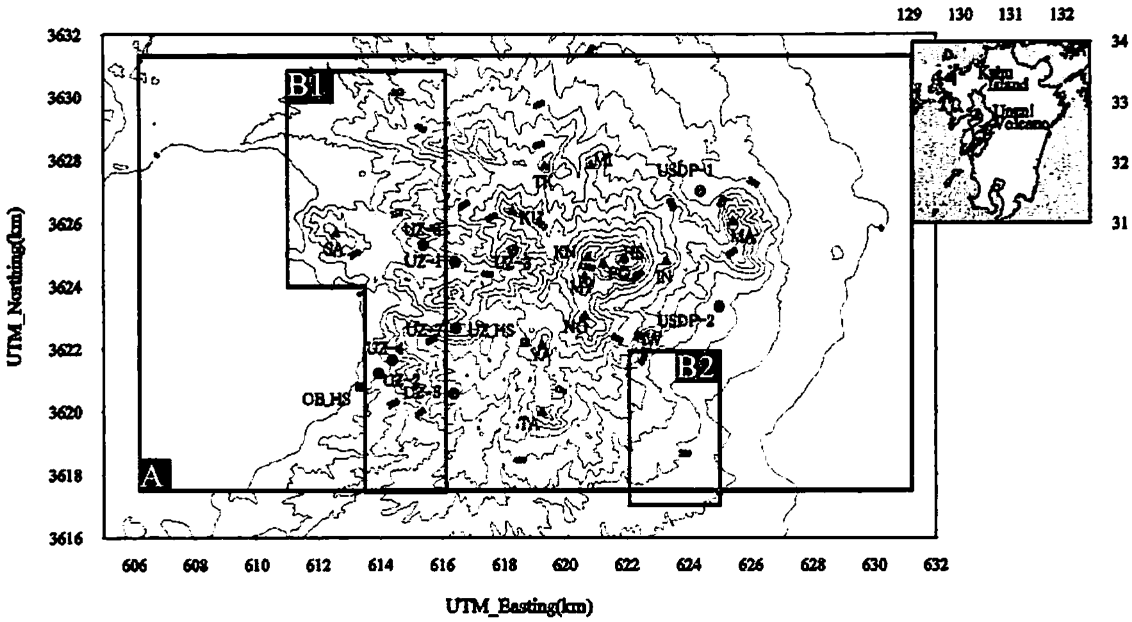

Fig.1. Topographic map of the central part of the Shimabara Peninsula. Contour interval is 100m. Box A shows the high-altitude aeromagnetic data area in 1991, and boxes B1 and B2 show the low-altitude aeromagnetic data area in 2002. Solid circles of UZ-1 to -7, and USDP-1 and -2 show the locations of drilling sites and numerals show the altitude (above sea level) of the top surface of basement rocks of Unzen volcano. Thick lines indicate normal faults after Hoshizumi et al. (2002). MA=Mayu-Yama; IN=Inao-Yama; IW=Iwatoko-Yama; FG=Fugendake; HS=Heisei-Shinzan; MI=Maidake; TK=Torikabuto-Yama; KN=Kunimidake; KU=Kusenbudake; MY=Myokendake; NO=Nodake; YA=Yadake; TA=Takaiwa-Yama; SA=Saruba-Yama; UZ-HS=Unzen hot spring; OB-HS=Obama hot spring.

2. Aeromagnetic Data

In Unzen Volcano, among several data sources of aeromagnetic surveys conducted at different epochs with varying survey specifications (NEDO, 1988; Nakatsuka, 1994; Mogi et al., 1995; Okubo et al., in press), the following two data are useful to discuss the tectonic and geothermal subsurface structure of the Unzen graben.

High-altitude data in 1991

An aeromagnetic survey covering the central part of the Shimabara peninsula was flown in August, 1991, after the commencement of recent eruption (Nakatsuka, 1994). Although it was before the formation of Heisei-Dome, the data from this survey is still useful, because it doesn't discuss on Heisei-Dome here. A total of 26 traverse lines in the E-W direction and 5 tie lines in the N-S directions were flown at an altitude of 7500 ft (2300 m) above sea level. Average line spacing of traverse lines is about 500m uncovering above the summit lava dome. Finally, Nakatsuka (1994) presented three-dimensional rough model of the graben by the analysis of the terrain corrected anomaly. However, further analysis in consideration of geological data was left.

Therefore, in order to discuss more detailed the tectonic and geothermal subsurface structure in the Unzen graben, we re-analyzed the same data, where the magnetic modeling are performed based on the results of magnetization intensity mapping by combining with drilling data of UZ-1 to -6 and USDP-1 and -2.

Low-altitude data in 2002

As low-altitude data, a helicopter-borne aeromagnetic survey was carried out on September 18, 2002. This survey was flown across the Futsu and the Fukae faults and across the Chijiwa and the Kanahama faults at a low altitude along the rugged topographic relief. The average flight altitude was about 500m above sea level. After the correction for terrain effect (cf. Bhattacharyya, 1964; Nakatsuka, 1981), we reproduced magnetic anomaly maps of boxes B1 and B2 at the reduction altitude of 850m above sea level using a procedure developed by Makino et al.(1993).

2. Data Analysis

Magnetization Intensity Mapping

In order to obtain information on the regional subsurface structure using the terrain corrected data, such as lava flows, pyroclastic flows, fructured and hydrothermally altered areas, we applied the magnetization intensity mapping method (e.g. Okuma, 1994; Nakatsuka, 1995;) by using data of Nakatsuka (1994). See Fig. 2.

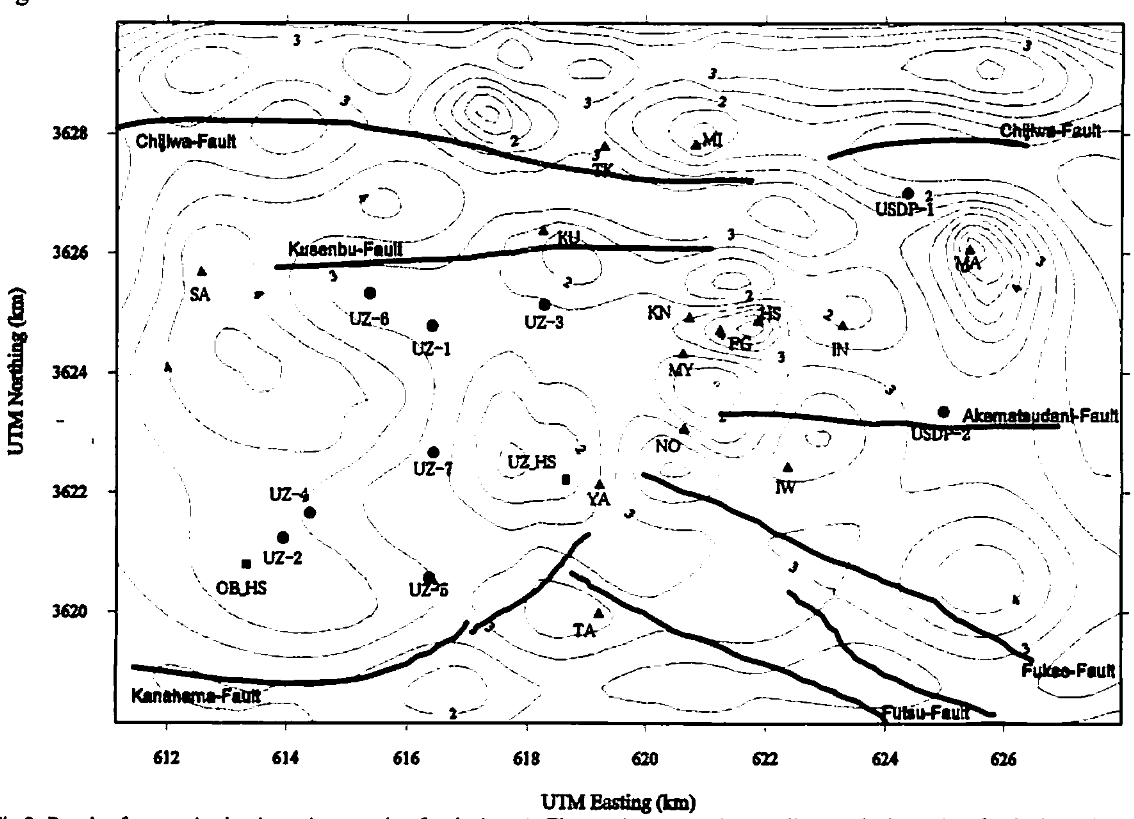

Fig.2. Result of magnetization intensity mapping for the box A. The terrain corrected anomalies are the input data for the inversion process.

Forward Modeling for Magnetic structure

We used 2.5 dimensional, foward-and-inverse magnetic profile modeling program (Webring, 1985). In order to simplify the modeling process, these terrain corrected anomalies were derived terrain reduced-to-pole aeromagnetic anomalies using the method by Baranov and Naudy (1964) (see Fig. 3).

The total magnetization used in this forward calculation is a vector sum of the induced and remanent magnetization. A 2.5D foward-and-inverse modeling along profiles crossing the main anomalies showed was performed. All the selected profiles produced by slicing this terrain reduced-to-the-pole magnetic anomaly grids are assumed that both the magnetic field and the magnetization vector are vertical.

We adopted the average magnetization intensities of 4.5 A/m for the Older Unzen volcano lava, and 1 A/m for the layers of the Pre-Unzen volcanics or the hydrothermally altered area, based on the result of the magnetization intensity mapping (Fig. 2). In addition, the magnetization intensity of the Mayu-Yama lava was assumed to 6 A/m, while the Younger Unzen, consisting mainly of collapse or lahar products of No-Dake, Myoken-Dake and Fugen-Dake, was assumed to 1 A/m, from the result of magnetization intensity mapping (Fig. 2). These results show in Fig. 4.

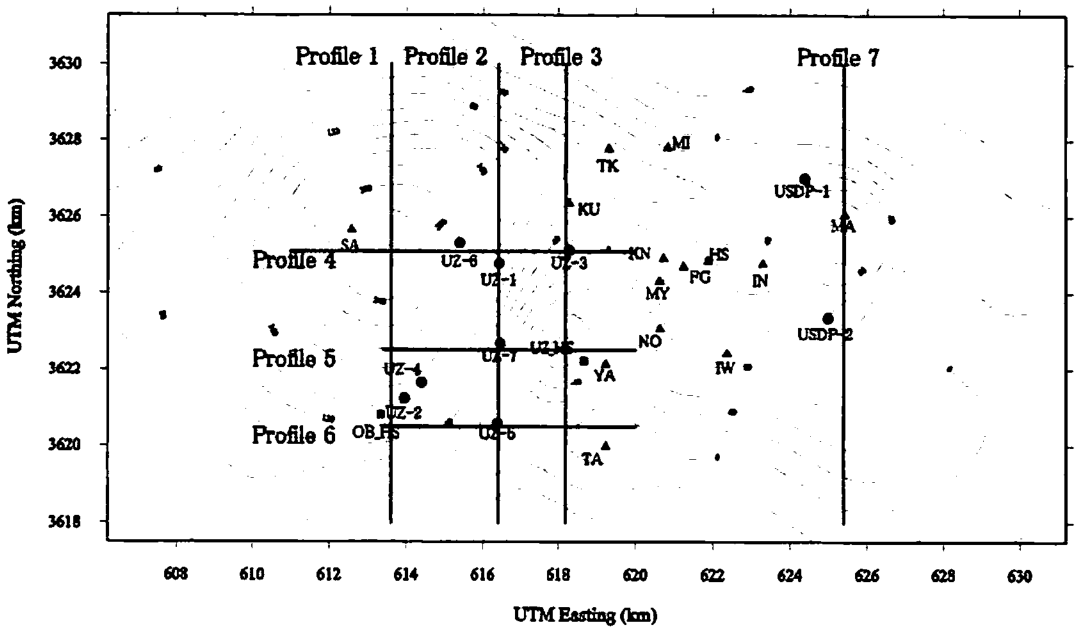

Fig. 3 Terrain corrected reduced-to-pole magnetic anomaly map of box A, and the locations of profiles of forward modeling. Contour interval is 20 nT.

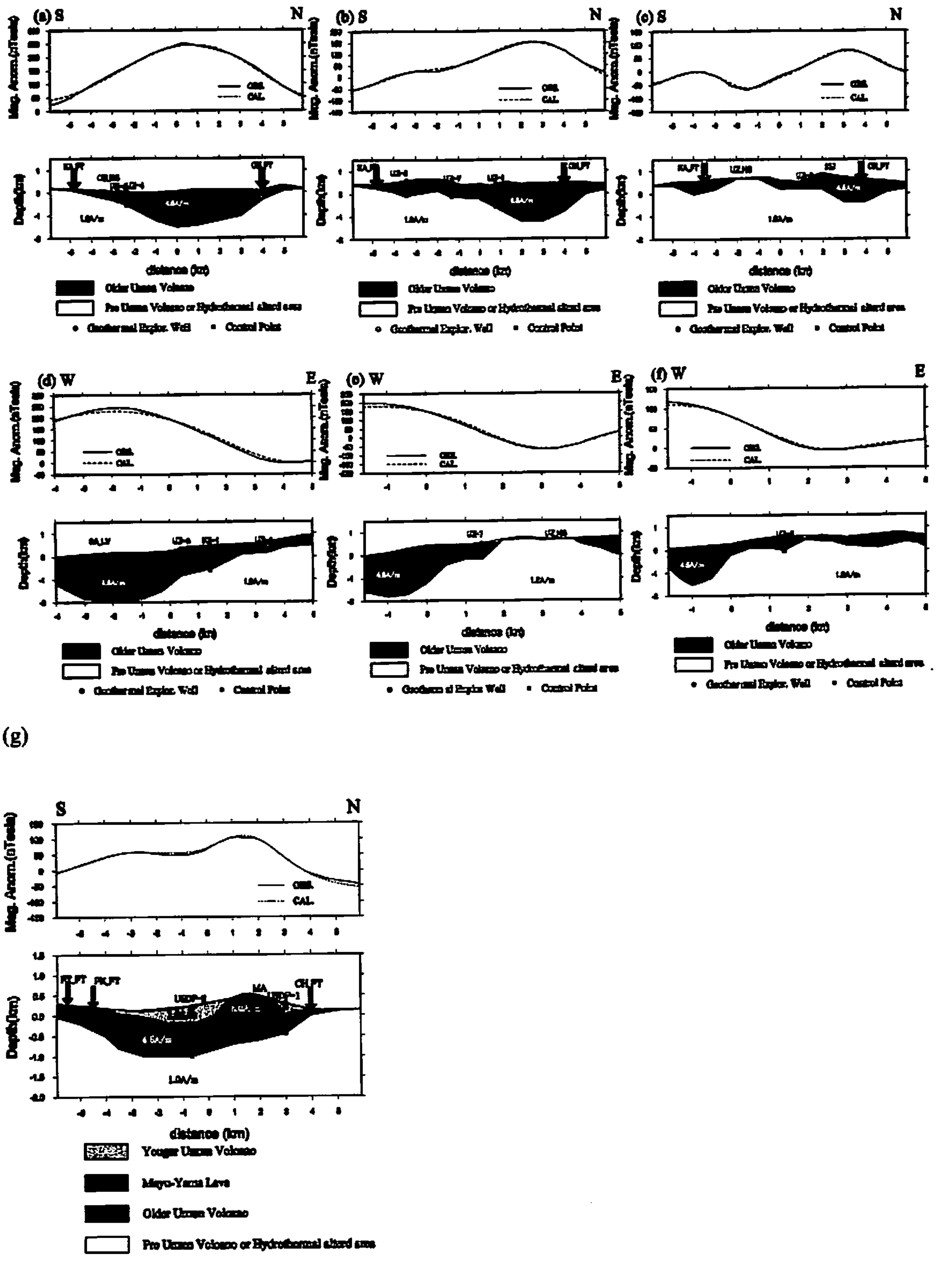

Fig.4 Results of the magnetic modeling along N-S profiles [(a) profile 1, (b) profile 2, (c) profile 3 and (g) profile 7] and E-W profiles [(d) profile 4, (e) profile 5 and (f) profile 6] shown in Fig. 3. Squares indicate the control points used for modeling after NEDO (1988).

Horizontal Gradients and Boundary Analysis

To lack the resolution, the high altitude data was not able to clarify the boundary of the main fault so much. Therefore, in this section, we performed horizontal gradients and boundary analysis using low-altitude aeromagnetic data, in order to understand more detailed and localized feature of the main faults qualitatively. In general, the lineaments delineated by the pseudo-gravity gradients represent deeper or more regional boundaries than those by the reduced-to-pole gradients (c.f. Blakely, 1995; Finn and Morgan, 2002).

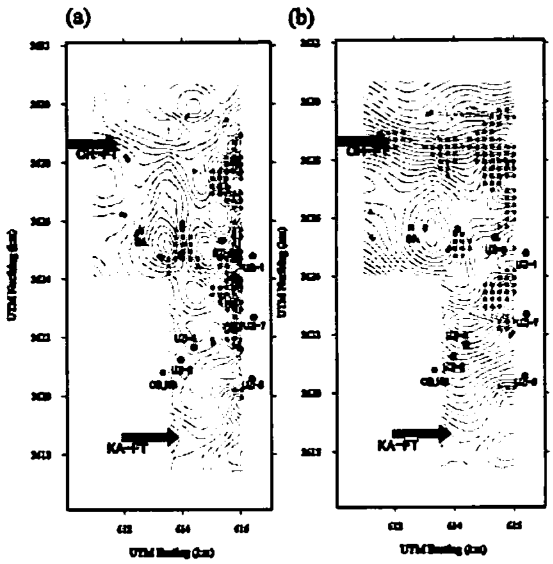

Fig. 5. Results of boundary analysis for the box B1 applied to (a) reduced-to-pole, and (b) pseudo-gravity anomalies of terrain corrected magnetic anomalies. Small dots indicate the peak areas in the horizontal gradient magnitudes (a) > 500 nT/km, and (b) > 1.6 Pseudo mGal/km. Line contours indicate (a) reduced-to-pole anomalies with the interval of 50 nT, and (b) pseudo-gravity anomalies with the interval of 0.2 Pseudo mGal/km, respectively. CH-FT=Chijiwa Fault; KA-FT=Kanahama Fault.

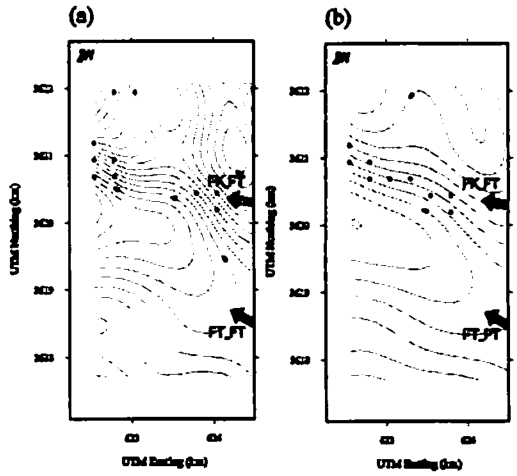

Fig.6. Results of boundary analysis for the box B2 applied to (a) reduced-to-pole, and (b) pseudo-gravity anomalies of terrain corrected magnetic anomalies. Small dots indicate the peak areas in the horizontal gradient magnitudes (a) > 250 nT/km, and (b) > 0.7 Pseudo mGal/km. Line contours indicate (a) reduced-to-pole anomalies with the interval of 20 nT, and (b) pseudo-gravity anomalies with the interval of 0.1 Pseudo mGal/km, respectively. FT-FT=Futsu Fault; FK-FT=Fukae Fault.

3. Summary

The western Unzen region

Chijiwa and Kanahama faults are known to be the basic frame of the graben in the western Unzen region. From our result of Figs. 2 and 4, it is suggested that lava and the pyroclastic flow of the Older Unzen are deposited thickly with the subsidence of the basement near the Chijiwa fault, while the subsidence of the basement is not clear at the Kanahama fault. The result indicates that the northern and southern faults forming the Unzen graben have different feature, and our result suggests that the subsurface structure in the western Unzen region has a feature of half-graben fallen at the northern fault. Also from the result of MT survey of Utada et al. (1994) and Kagiyama et al. (1992), it is known that the thick layer of high resistivity exists near the Chijiwa fault, while the layer of low resistivity exists under the surface near the Kanahama fault. Therefore, it is also consistent with the result of MT survey.

On the other hand, magnetization lows (about 1 A/m) are distributed around Unzen hot spring and Shimo-Dake (UZ-3). It is difficult to distinguish whether they are the formation of the Older Unzen or the Pre Unzen (basement) from aeromagnetic data only. In particular, our magnetic model demonstrated that the layer of low magnetization (1A/m) extends near surface beneath Shimo-Dake and Unzen hot spring (Fig. 4). According to drilling data (NEDO, 1988) at UZ-3 and other sites, the layer corresponds generally to the hydrothermal alteration or fractured rocks. Kagiyama et al. (1992) also showed that the layer of low resistivity becomes extremely shallow around Unzen hot spring to reach surface at Unzen hot spring. Therefore, it is thought that the rises of the low magnetization layer correspond to the fractured or hydrothermally altered zones caused by the upflow of geothermal convections. Thus, the layer of low magnetization are dominated at Unzen hot spring and at the area from Shimo-Dake to Kamidake reflecting hydrothermal alteration (Fig. 2 and Figs. 4(c) and (e)). However, no magnetization lows are found at Obama hot spring (Fig. 2 and Figs. 4(a) and (f)). It is expected that the scale of the geothermal convection system at the Obama hot spring is much smaller than the one of Unzen hot spring.

The eastern Unzen region

In the volcanic fans extending southwards, it turns out that the basement was much depressed in the stage of Older Unzen and a thick distribution of the Older Unzen products inside the graben (Fig. 4) exists beneath the younger deposits. In particular, it is shown in our magnetic analysis that the basement subsidence at Fukae fault is remarkable (see Fig. 6). It seems that the axis of the Unzen graben moves south toward east in the Shimabara peninsula (Fig. 4). Thus, the magnetic structure in the western Unzen region has the feature of half-graben fallen at southern fault. The same tendency has been shown also in the geologic cross-section by Hoshizumi et al. (2003) and in the 2D analysis of gravity basement structure (Inoue and Takemura, 2002).

The magnetization intensity of Mayu-Yama lava is much higher than other lavas in Unzen Volcano, which is consistent with the result of analysis from another aeromagnetic data by Mogi et al., (1995). As an evidence from the paleomagnetic study of Unzen (Tanaka et al., 2004), Mayu-Yama lava shows the NRM intensity higher by one order of magnitude than the average of those in the central Shimabara peninsula.

On the other hand, magnetization lows are dominant along Chijiwa fault and on the circumference of Mayu-Yama (Fig. 2). There are two possibilities of causing these magnetization lows. First, they may reflect the distribution of fan deposits of the Younger Unzen in the shallow parts. These rock bodies, even though having remanent magnetization, were fractured into pieces and rotated into random directions. Another possibility is that high-temperature geothermal fluids may cause the hydrothermal alterations of volcanic rocks. Actually, high HCO_3 concentrations are observed around Mayu-Yama and Shimabara and they are believed to come from the addition of CO_2 gases of deep origin ascending along the faults such as the Chijiwa and the Akamatshu-Dani faults (Kazahaya, 2002).

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