Delineation of Late Miocene to Pleistocene Caldera Rims from Gravity and Aeromagnetic Data

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Abstract: We proposed an algorithm to delineate caldera rims using gravity and aeromagnetic data. Considering that major calderas in the study area have significant regional depression on both data, a standard DEM (digital elevation model)-based hydrologic algorithm was conducted to each data to delineate caldera rims of Northeast Honshu. The resulted rims were compared to the manually interpreted rims of calderas of the same areas. From both data, 54% of the existing calderas were delineated. Although gravity data is likely superior to aeromagnetic data on identifying calderas, the aeromagnetic data detected some rims that undetected by the gravity data.

Key-Words: caldera rim, landslide, gravity data, aeromagnetic data

1 Introduction

In the last decade, many studies investigated the relationships between landslides and calderas in Northeast Honshu, Japan [1,2]. Those calderas with ages ranging from late Miocene to Pleistocene are mainly distributed along the volcanic front, Ou Backbone Range. Because landslides occurred mostly inside the calderas or along their rims, a quantitative analysis is important to delineate the rims.

The topographic caldera rim is simply the escarpment that bounds the subsided area of a caldera. For eroded calderas, erosional mass wasting first tends to enlarge the original topographic rim, but later erosion of outer slopes of the upper caldera edifice can also reduce the apparent topographic diameter [3]. Although many circular feature detections for geo-scientific applications were presented, most of them aimed to identify impact craters [4,5]. For old calderas, however, the interpretation of the topographic rims may vary because preserved rims are not always obvious [6]. Conventionally, caldera rims are observed using geology, topography and geophysical data such as gravity and aeromagnetic. However, disagreement often occurs between observers on determining rims [7].

Williams [8] suggested that caldera types could be divided into groups distinct in geophysical properties. The gravimetric method proves to be effective to study the structures of calderas [9] because calderas

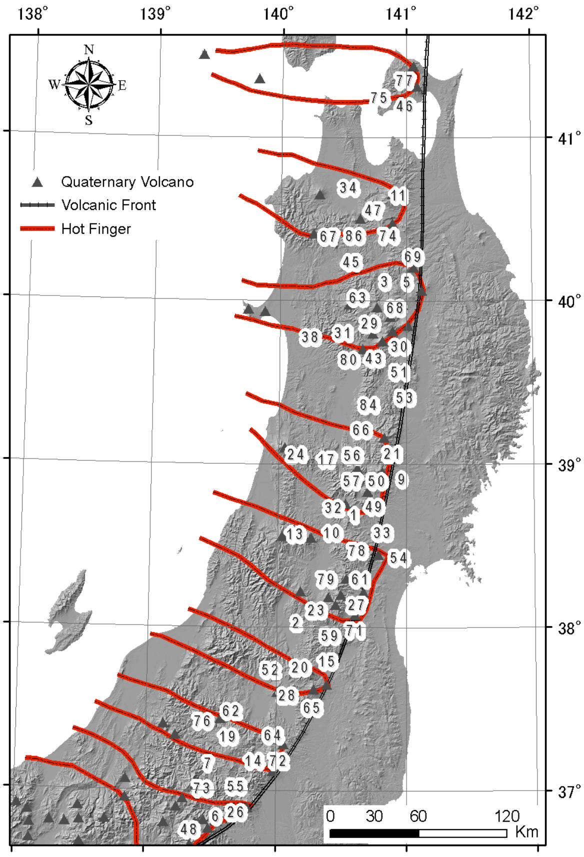

Figure 1. Calderas of Northeast Tohoku draped over a shaded relief. Each caldera is numbered for convenience of reference for the analysis.

were formed with the movements of a huge amount of volcanic ejecta [10]. Greene and Plouff [11] indicated location of a caldera using gravity and aeromagnetic data.

This paper proposes an algorithm to delineate topographic caldera rims with ages ranging from late Miocene to Pleistocene on gridded gravity and aeromagnetic data. The rims are evaluated with the manually interpreted caldera rims of the same areas.

2 Study area

Fig. 1 shows 87 calderas distributed in Northeast, Japan for this study. The study area is located at a subduction zone, where the Pacific plate is subducting as rapidly as 10 cm/year [12]. Many shallow earthquakes occur associated with this subduction. Many of them are concentrated in a long, narrow zone extending along the volcanic front (Ou Backbone Range), which run through the middle of the land area nearly parallel to the trench axis [13]. All calderas in this area are located along the volcanic front. They form a group inside the hot fingers in the mantle wedge inferred by Tamura et al. [14].

3 Data

3.1 Gravity data

Grid data of Bouguer gravity anomalies, published by the Geological Survey of Japan [15], used in this study were created from gravity measurement of 347,979 points in land and 691,766 points in ocean area. The values of Bouguer correction and terrain correction are given with an assumption that rock density is 2.0, 2.3 and 2.67 g/cm3. The resulted gravity data had 1 km grid spacing and was projected using the polyconic projection. For this study, the gravity data were converted into the Universal Transverse Mercator (UTM) and interpolated to create 200 m grid spacing.

3.2 Aeromagnetic data

The aeromagnetic data, published by the Geological Survey of Japan [16], used in this study were accumulated from aeromagnetic survey for geothermal assessment conducted by the New Energy

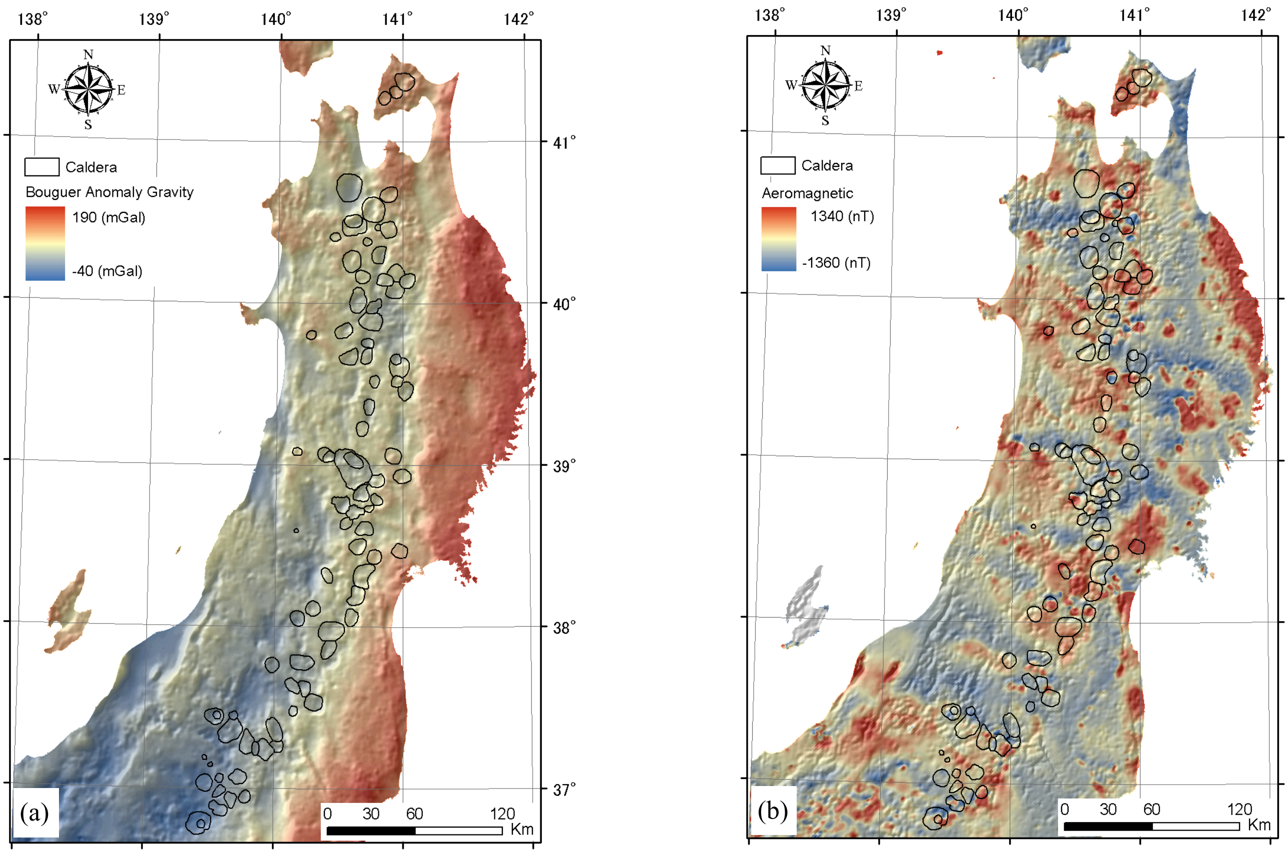

Figure 2. Gravity (a) and aeromagnetic (b) data used for this study. Colors of both data were shaded with a solar azimuth of 360° and at a solar elevation of 45° to show details of relief inside the calderas.

Development Organization (NEDO). The survey flights were made mainly over land, and the data were combined with GSJ data of mainly offshore, to compile aeromagnetic maps of Japan. The grid spacing was 200 m and projected using UTM [17].

Fig. 2 shows the gravity and the aeromagnetic data for this study. The caldera rims were compiled from variable sources [18]. Calderas are draped over these maps to show their visual characteristics against both data.

3 Caldera rim delineation

The statistic values of gravity and aeromagnetic data inside calderas have considerable variation. However, most calderas in the study area have regional depression in both data as observed in fig. 2. We have also confirmed that no serious non-normality in values for gravity and aeromagnetic data for any calderas. Therefore, it seems very possible that the center and the boundary of the depression represent those of the caldera. Delineating

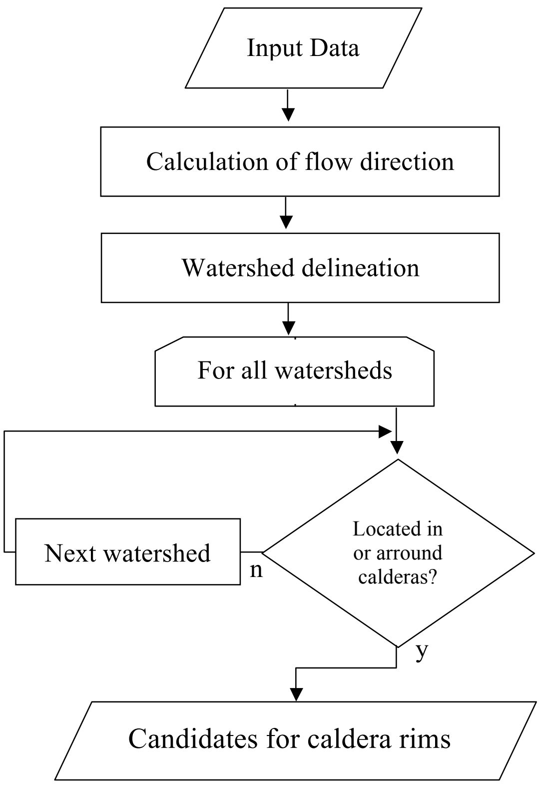

Figure 3. The proposed algorithm to deliniate caldera rims. The resulted rims are then evaluated with the corresponding manually interpreted rims.

boundaries of depressions is similar with that of watersheds from a digital elevation model (DEM) using hydrological modeling [19], with an exception that sinks removal process is not needed.

Fig. 3 shows our proposed algorithm to delineate caldera rims from gravity and aeromagnetic data. Each data are processed separately with this algorithm. The values of each data are treated as elevation data to allow calculation of flow direction from or to each cell. A cell, in which its flow direction can not be defined, is marked as a sink. A watershed is the total area of water flowing to a given sink. Therefore, deliniating a watershed can be done by tracing the outer cells contributing the flow to the sink. This process will produce many watershed of the entire study area. Because calderas distributed mainly along the volcanic front and inside hot fingers, the resulted watershed apart from these areas can be eliminated. The remained watersheds and their boundaries will be candidates for calderas and their rims.

4 Results

Candidates for caldera rims were delineated from gravity anomaly data, and from aeromagnetic data. We used gravity data that was corrected based on assumed rock density 2.67 g/cm^3, the average of assumed density of the granitic rocks. Kudo et al. [20] indicates that crustal structure of Northeast Honshu can be effectively observed using Bouguer gravity anomaly corrected by this assumed density.

The candidates of caldera rims extracted by the proposed algorithm were compared with the manually interpreted rims (fig. 2). The results were ranked on a scale of “A” to “C” in order of coincidence between rims. “A” and “B” represent excellent and good in term of coincidence, respectively. A rim ranked as “A” accurately coincides with the manually interpreted rim, and in some cases it shows better boundary. A composite of adjacent rims coincides with the manually interpreted rim is also ranked as “A”. On the other hand, a rim ranked as “B” does not completely cover the manually interpreted rims, but its boundary mostly represents the corresponding caldera rim. A rim ranked as “C” covers the manually interpreted rim widely but its boundary does not represent the caldera rim.

Table 1. Calderas delineated by this study. Numbers associate calderas with their location in fig. 1. The ratings A to C represent the quality of delineated rims from each data.

No	Name	Size (km x km)	Age (Ma)	Data Grav.	Data Aero.
1	Akakura	9 x 9	3.3	A	-
2	Akayu	10 x 10		C	C
4	Aonokimori	7 x 7	2.1	B	-
7	Furumachi	3 x 3		C	C
9	Genbi	10 x 9	7-6, 5.1, 5.7	A	C
11	Hakkokuda	10 x 9	0.65, 0.40	B	-
12	Hanayama	8 x 8	9.2±2.64	A	-
13	Hijiori	2 x 2	11-8.8Ka	C	-
15	Iizaka	12 x 8		B	-
18	In-nai (outer)	8 x 8	5.0-4.5	A	-
22	Joko	6.5 x 6.5	4.1	C	-
23	Kaminoyama	10 x 10	7-5	A	-
24	Kamitamatagawa	6 x 5	5.9-3.4	C	C
25	Kawafune	9 x 7	5.27, 6-5	-	A
26	Kawaji	10 x 7	7.3-6.8	-	C
28	Kijigoya	13 x 7	10.0±1.1	-	C
29	Ko-Tamagawa	18 x 16	1.93-1.77	-	B
31	Miyata	10 x 8	6-5	-	A
32	Mukaimachi	13 x 12	7.5-6, 2.4-1?	A	-
33	Nagashida	8 x 7		-	C
34	Namioka	27 x 16		C	-
35	Nanatsu-mori	9 x 8	3.5	C	C
36	Naruoka	9 x 5	1.11	A	-
38	Nibetsu	6 x 5		C	-
39	Nigorikawa (Akita)	5 x 4	4-3	C	-
46	Ohoudake	8 x 7	3.5-1.9	C	-
47	Okiura	18 x 16	1.6-0.9	B	-
49	Onikobe	10 x 10	2.4-1.5, 1.7-0.25	A	-
50	Onomatsuzawa	13 x 10		B	-
52	Otoge	10 x 10	7-6	B	-
53	Rokuroyama	11 x 9	10-7	A	C
58	Sen-yakeyama	10 x 8	1-0.7	A	-
59	Shichigashuku	16 x 12	7-6, 5-4	B	-
64	Takagawa	16 x 10	6.5-6.3	C	-
67	Tashiro	6 x 5	13-8	C	-
74	Towada	13 x 12	0.40-0.001	C	-
75	Ushitaki	8 x 8	1.93	A	A
76	Uwaigusa	13 x 10	4.1-3.9	A	-
77	Yagen	11 x 10	4-3.5	C	C
78	Yakuraisan	10 x 10		A	-
79	Yamadera	9 x 6	9-6?	-	A
80	Yamaya	13 x 10	8-7	B	-
81	Yashioda	3.3 x 2.8		-	C
82	Yaso	6 x 4	3.50-3.64	A	-
83	Yokomuki	12 x 12	5.3-5.0	C	B
84	Yuda	8 x 4	6-5	C	-
86	Yunosawa	16 x 12	3.55-2.3	A	-

i) Some calderas with ages remain undefined are leaved blank or question marked.
ii) Grav.: gravity data, Aero.: aeromagnetic data

Table 1 shows that 47 significant rims were successfully extracted from the data. This number is equivalent to 54% of the total number of calderas in the study area. For an initial attempt to delineate rims, this result shows that the proposed algorithm is effective. Of the total rims extracted from gravity data, fifteen were ranked as "A", eight as "B", and sixteen as "C" while from aeromagnetic data, four were ranked as "A", two as "B", and eleven as "C". Although the gravity data seem to be superior on detecting calderas, eight rims undetected by this data were recognized by the aeromagnetic data. Fig. 4 shows samples of rims ranked as "A" to "C". Hill shading images in the backgrounds show that these calderas are difficult to observe from topographic data. These results show that the caldera structures are still preserved in gravity and aeromagnetic data.

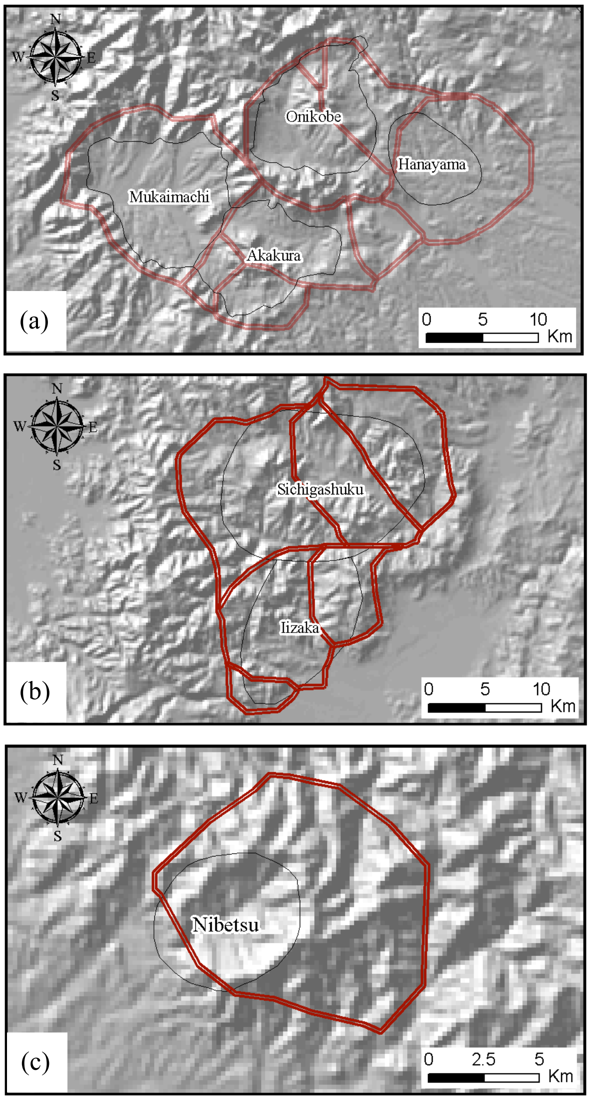

Figure 4. Samples of extracted rims (double line) againts manually interpreted rims (solid line): (a) A-ranking, (b) B-ranking, (c) C-ranking.

5 Conclusion

Our proposed algorithm shows that old caldera rims can be delineated using gravity and magnetic data. Once the flow directions are calculated, the centers of the depressions (sinks) can be detected. Popular GIS softwares enable user to create watersheds from assigned sinks interactively. This paper extends this functionality to delineate caldera rims. The improvement of this algorithm and the detail structures of caldera reveal from this algorithm will be presented in our next full paper.

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