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APLICATION OF HORIZONTAL GRADIENT AND EULER DECONVOLUTION METHODS FOR GRAVITY DATA ANALYSIS OF BATUR VOLCANO, BALI, INDONESIA

Tajudin Noor[1], Supriyanto[1], Mochamad Nur Hadi[2] and Dendi Surya Kusuma[2]

[1]Dept. Of Physics, Faculty of Mathematics and Sciences, University of Indonesia, Kampus UI Depok, 16424
[2]Geological Resources Center, Jl. Soekarno Hatta No. 444 Bandung 40254
Email: aji.tajudinnoor@gmail.com

ABSTRACT

Mount Batur is an active volcano located at the center of two concentric calderas north-west of Mount Agung, Bali, Indonesia. The south east side of the larger 10×13 km caldera contains a caldera lake. Batur caldera formation on the geology consists of geologic rock formations containing Batur volcano agglomerates, lavas and tuffs. This area has been in the preliminary study phase of geology, geochemistry, and geophysics for geothermal exploration. As one of the geophysical study, the gravity of the area was surveyed in an attempt to delineate the subsurface structure and to better understand the relationship between the geothermal systems and the subsurface structure. The gravity bouguer anomaly data were analyzed using integrated gradient interpretation techniques, such as the Horizontal Gradient (HG) and Euler Deconvolution (ED) methods. These techniques detected boundaries of body anomalies and faults structure that were compared with the lithologies in the geology map. The analysis result will be useful in making a realistic subsurface mapping of Batur volcano, Bali.

Keywords: gravity data, horizontal gradient, euler deconvolution, Batur volcano-Bali.

INTRODUCTION

Mount Batur is an active volcano located at the center of two concentric calderas north-west of Mount Agung, Bali, Indonesia. It is about 70 km north of the capital city of Bali, Denpasar. This area has been in the preliminary study phase of geology, geochemistry, and geophysics for geothermal exploration. Regarding the geophysical data, some measurements including gravity, resistivity and magnetotelluric surveys have been conducted by the Pusat Sumber Daya Geologi, Badan Geologi in 2012. This study focuses on the analysis and interpretation of gravity data from the Batur volcano and aims to understand the subsurface structure around it and its relationship to geothermal manifestations.

GEOLOGICAL SETTING

The Batur volcano, situated in northern Bali, forms part of the Sunda Arc system, which reflects northward subduction of the Indo-Australian plate beneath the Eurasian plate (Hamilton, 1979). The crust beneath Bali is about 20 km thick, with an oceanic velocity structure (Curray et al., 1977). The Benioff zone lies at about 150 km (Hamilton, 1979). Most of the island consists of Tertiary to Quaternary volcanic rocks, with the southern part formed from uplifted coral reefs of Pliocene–Pleistocene age (Kadar, 1977). The central part of the island is comprised of four late Quaternary volcanoes or volcanic fields: Batukau, Bratan caldera (including several post-caldera stratovolcanoes), Batur and Agung, the last two active in historical times.

Volcanic activity within the Batur volcano may be divided into six main periods (Reubi, 2004; Sutawidjaja, 1990; Figure 1):

1. Building of a basaltic to andesitic stratovolcano (Penulisan volcano) in the north-western sector. Palaeotopographic reconstructions suggest that this volcano was at least 2,200 m high and 20 km in diameter prior to the collapse of the first caldera. Two lava flows from this volcano have been dated by the K–Ar technique at 510±20 and 310±20 ka, respectively (Wheller and Varne, 1986). During this period an 800-m-high basaltic to dacitic parasitic cone (Abang volcano) also formed on the SE flank of the main edifice. Lavas from this cone contain no detectable radiogenic Ar, indicating ages of less than 100 ka (Wheller and Varne, 1986).

2. Collapse of the first caldera (CI), associated with the eruption of dacitic ignimbrite (Ubud Ignimbrite) dated by C14 at 29,300 years b.p. (Sutawidjaja, 1990). This caldera was centred between the two older edifices and intersected both of them. Its topographic shape is elliptical, with a 13.5-km-long, NW-trending major axis.

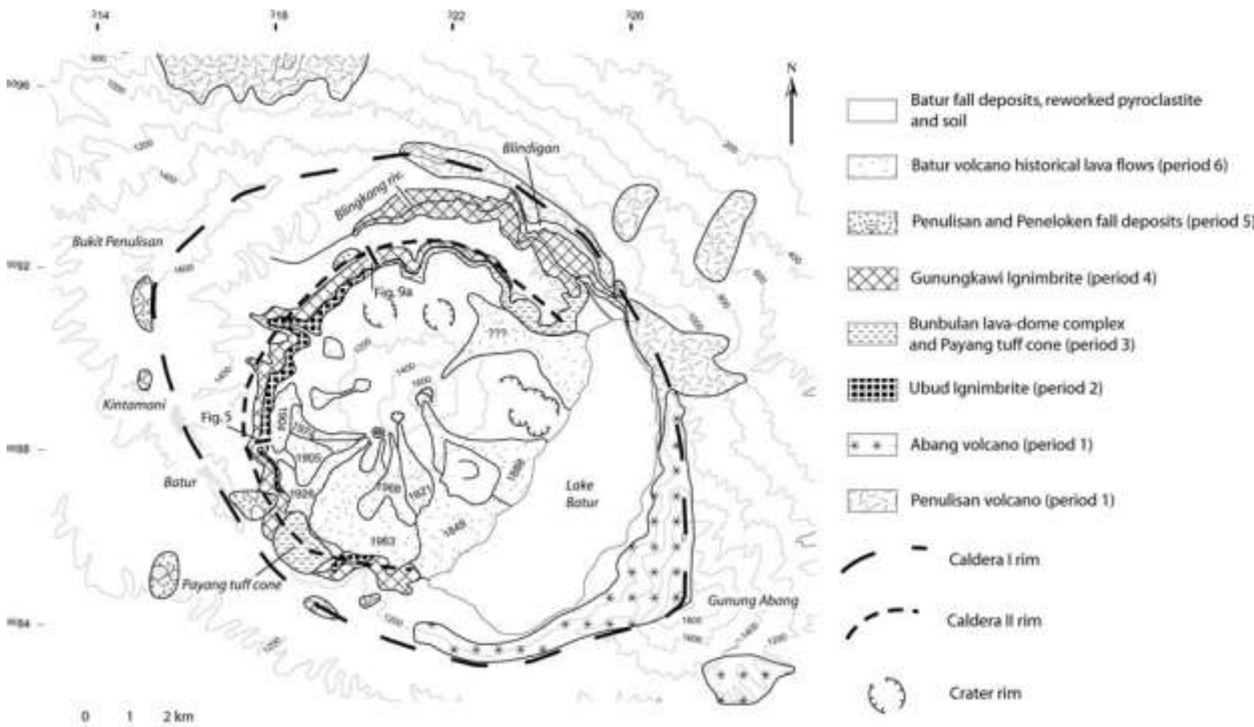

Figure 1: Sketch geological map of Batur Volcanic Field (after Sutawidjaja, 1990)

3. Formation of an andesitic to dacitic lava-dome complex (Bunbulan lava-dome complex) and a small tuff cone (Payang tuff cone) within the CI depression.

4. Collapse of the second caldera (CII), again accompanied by eruption of andesitic to dacitic ignimbrite (Gunungkawi Ignimbrite), dated by C14 at 20,150 years b.p. (Sutawidjaja, 1990). This caldera formed within the older CI caldera. Its exact shape is unknown as the SE sector is covered by younger lavas and Batur Lake. However, the visible portion suggests an elliptical shape with a 7.5-km-long, NE trending major axis.

5. Andesitic to dacitic explosive activity producing pyroclastic fall deposits (Peneloken and Penulisan fall deposits of Sutawidjaja, 1990). Based on maximum pumice size distribution, the source of these deposits is believed to have been within CII (unpublished data).

6. Building of the historically active, 1,700-m high, basaltic andesite Batur stratovolcano within CII.

GRAVITY METHOD

In principal, the goal of gravity surveying is to locate and describe subsurface structures from the gravity effects caused by their anomalous densities. Gravity studies in volcanic areas, in particular, can provide unique insights into shallow sub-surface density variations associated with the structural and magmatic activity of a volcanic system (Rymer and Brown, 1986).

A total of 296 stations for gravity survey in the Mount Batur were carried out. As a part of the gravity data analysis, tidal, latitude, free-air, Bouguer and terrain corrections were then applied to the gravity data. A discrepancy between the corrected, measured gravity and the theoretical gravity is called a gravity Complete Bouguer Anomaly (CBA).

Horizontal Gradient

The horizontal gradient method was used extensively to locate the boundaries of regions of contrasting density from gravity data (Cordell, 1979). The greatest advantage of the horizontal gradient method is that it is least susceptible to noise in the data because it requires the calculation of only two first-order, horizontal derivatives of the field (Phillips, 1998).

$$H(x,y) = \sqrt{\left(\frac{\partial G}{\partial x}\right)^2 + \left(\frac{\partial G}{\partial y}\right)^2} \qquad (1)$$

The map of horizontal gradient from Batur area is shown in Figure 2. It shows that the Batur caldera are located at the maxima of the horizontal gradient. Some new faults were detected as well. These faults

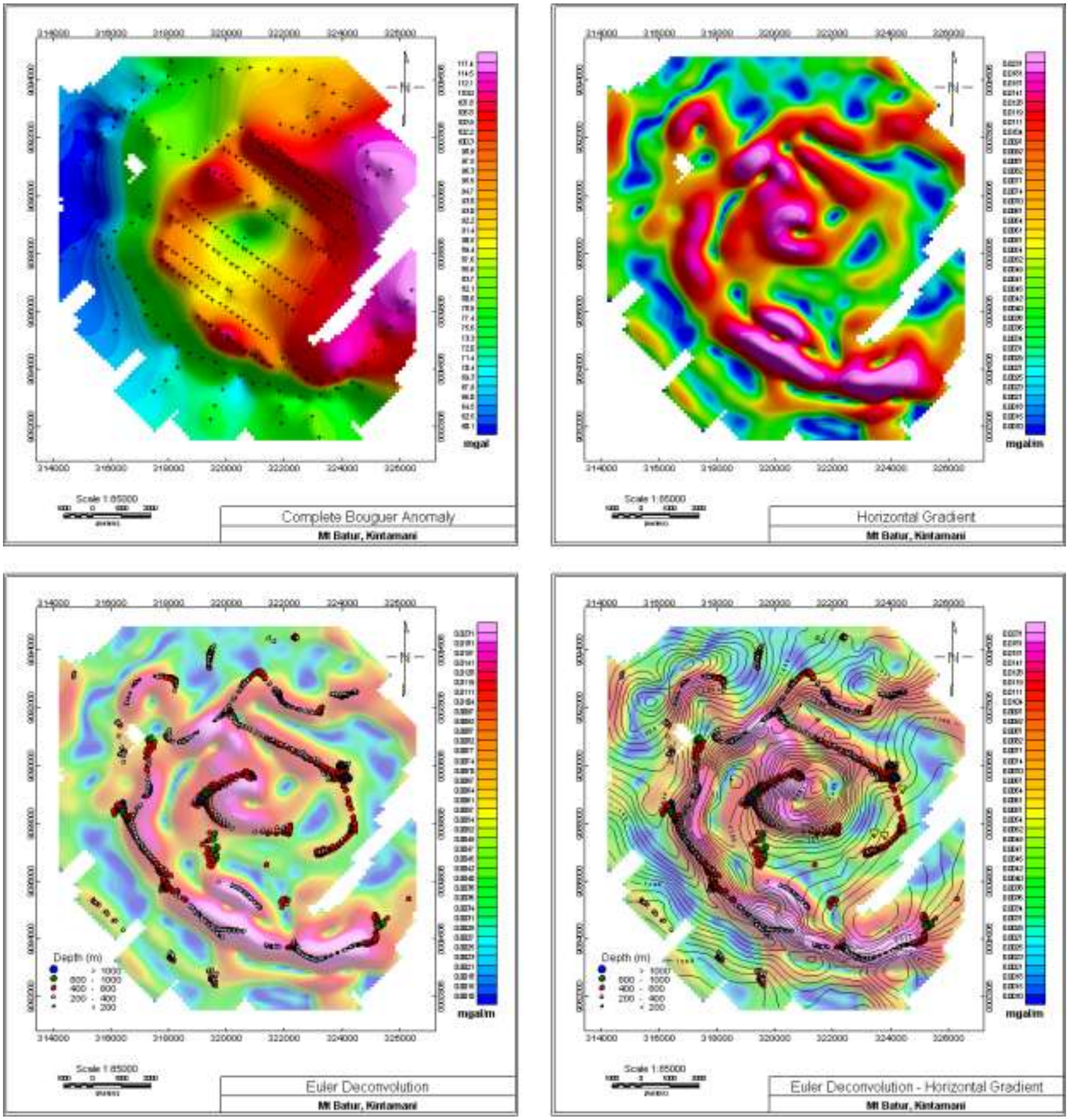

Figure 2: Maps of gravity data analysis using Horizontal Gradient and Euler Deconvolution methods

are located at, or near, the hot springs in the area. Moreover, some geological faults are not corroborated by the horizontal gradient technique. This discrepancy may be the fact that the horizontal gradient detects only faults that displaced formations vertically causing density contrasts.

Euler Deconvolution

The Euler Deconvolution is used to estimate the depth and location of gravity source anomalies. The Euler Deconvolution equation in 3D is given by Reid *et al*. (1990)

$$(x - x_0)\frac{\partial g}{\partial x} + (y - y_0)\frac{\partial g}{\partial y} + (z - z_0)\frac{\partial g}{\partial z} = n(\beta - g) \quad (2)$$

Euler solutions are estimated to gravity data using a structural index (SI) of 0 for faults and contacts. The Euler depth map is shown in Figure 2 and indicates that the depth to the gravity sources ranges from 0.5 to 1.5 km. The Euler method, for this source geometry, estimates the depth to the top of the source, meaning that 0.5 km to 1.5 km represents the top of the source. Distinct gravity high anomaly is encountered in the centre part of study area. It could be inferred that the volcanic rock intrusion may located on that area. Furthermore, some steep gravity gradients are found following the boundary of gravity high. This steep gravity gradient that is detected by the Euler method has good agreement with the Batur caldera structures and lineaments surrounding gravity high. The Euler solution has expected fault structure at Toya Bungka hot springs. This solution could be interpreted as a densification due to mineralization within fractures intersection. This phenomenon is similar to that found in the Broadlands-Ohaaki geothermal field in New Zealand (Hochstein and Henrys, 1989). Meanwhile gravity high which is encountered in the eastern part could not be interpreted because there are not enough stations in this area.

CONCLUSION

The gravity data analysis using Horizontal Gradient and Euler Deconvolution methods provided a better understanding of the structure of the Batur volcano and allowed us to detect additional faults. This analysis also indicates that this caldera is structurally controlled. The new structural map derived from the interpretation of the gravity data, when combined with other geological, geophysical, hydrogeochemical and numerical models, provides an effective tool for analyzing potential geothermal system and subsurface structure in study area.

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