

Integrated Geophysical Studies of Palu-Koro Depression Zone, Indonesia: Implications for Geothermal Resources in Bora Central Sulawesi

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ABSTRACT

The Palu-Koro depression zone, here in referred to as the study area, covers the Bora geothermal field. It is a non-volcanically hosted geothermal area, lying approximately 30 km to the south of Palu, the capital city of the Central Sulawesi Province, and belongs to Sigi-Biromaru Regency. The study area is characterized by geothermal surface manifestations consisting of hot waters (90.1 °C), hot ground (100.6°C), and altered rocks. The area is overlain by Quaternary sediment, Tertiary plutonic intrusive rocks and Pre-Tertiary metamorphic rocks. The terrain is characterized by extensive faulting forming numerous almost N-S trending ridges and fault scarps.

The objective of the geophysical survey carried out (gravity, geomagnetic and magnetotelluric measurements), was to delineate a heat source, the possible boundaries of the geothermal reservoir and deep structures controlling the flow of geothermal fluid, and evaluate the geothermal resource potential of the area. The integrated geophysical studies in the area indicate that the Bora geothermal system lies at the floor of the Palu-Koro depression zone which is considered associated to tectonic activities (Palu-Koro fault) that trend approximately N-S. These structures also control where geothermal manifestations in the area are seen on the surface. The heat source is considered to be associated with young plutonic rocks, resulting from tectonic activities.

1. INTRODUCTION

The Central Sulawesi Province is dissected longitudinally by the Palu-Koro fault system, here in referred to as the Palu-Koro depression zone, where geothermal fields and prospects of low to high temperature (37-100.6°C) are located (Figure 1). These geothermal fields are of non-volcanic origin, (Idral 2010), and are believed to be associated with plutonic intrusives and fracturing of the Palu-Koro fault and related tectonic activities.

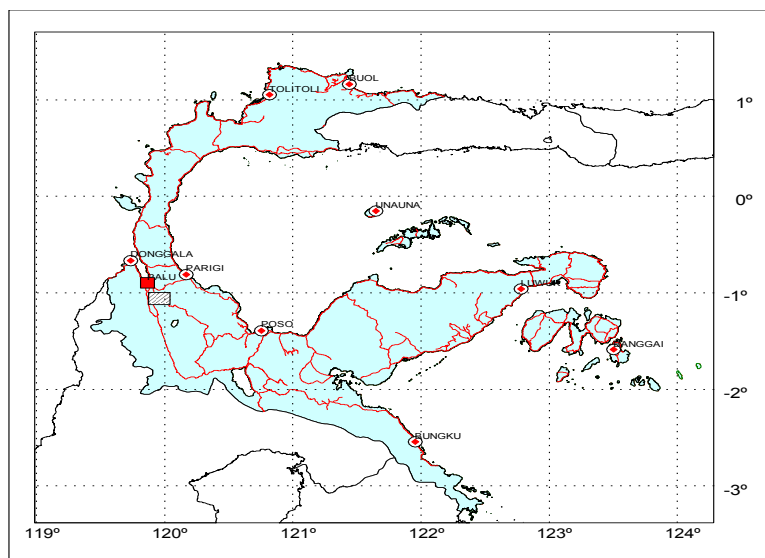


Figure 1: Location of the survey area and the Bora depression zone

The geothermal prospect is characterized by hot water, hot ground and altered rock (argillic-advance-argillic) that is found around the manifestation area. The prospect area is overlain by Quaternary sediments, Tertiary plutonic intrusives and Pre-Tertiary Metamorphic rocks (Sumadirdja, 1973, Sukido, 1993, Simanjuntak, 1997, and PMG-A, 2010). Extensive faulting (normal and oblique faults) accompanied by tilting characterize the terrain and forming numerous ridges and fault scarps trending nearly N-S, (Simanjuntak, 1997, PMG-A, 2010) associated with young intrusives that intrude the Tertiary plutonic rocks.

Recent geochemistry work by PMG (2010) indicates that a geothermal reservoir exists in the Bora depression zone. The reservoir temperature ranges is assumed to be in the range 113-239°C (based on Na/K temperature by Giggenbach) (PMG-A, 2010).

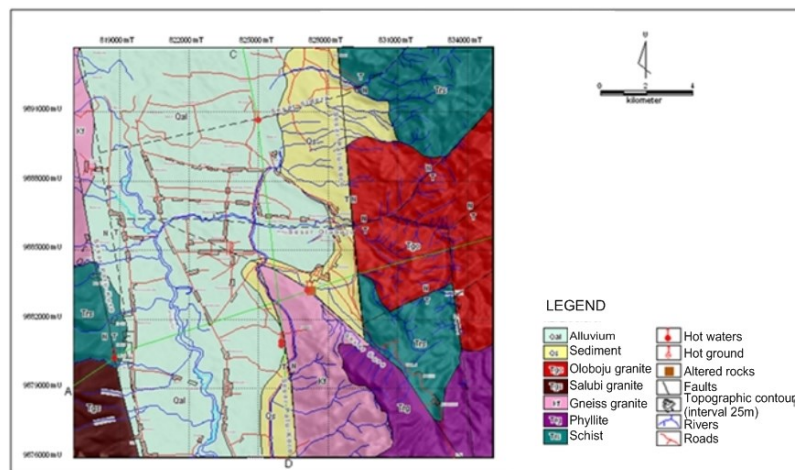


Figure 2: Geology of the Bora depression zone (Sumadirdja, 1973, Simanjuntak, 1997, PMG-A, 2010)

The area has been studied for the purpose of developing a geothermal power plant, if feasible. Therefore, an integrated geophysical survey (gravity, geomagnetic and MT measurements) was carried out to delineate the geothermal resource, the possible boundary of the geothermal reservoir, deep structures that control the geothermal fluid and evaluate the geothermal resource potential of the area. In this paper, we present the result of this study undertaken in the Palu-Koro depression zone, which was a part of an intensive geothermal resource exploration program in Indonesia.

2. PREVIOUS WORK

Before the end of 2008, no significant exploration had been carried out on the geothermal manifestations in the Bora depression zone, except for geological mapping. The regional mapping was conducted, on and off, by governmental institutions in the period 1973-1997, including the Geological Survey of Indonesia (GSI: Sumadirdja, 1973, Sukido, 1993, and Simanjuntak, 1997), Directorate of Volcanology, Directorate of Mineral Resources and others. In 2009, PMG carried out the *Joint study on non-volcanically hosted geothermal systems in the central part of Sulawesi*. And a year later, in 2010, an integrated geological, geochemical and geophysical (gravity, geomagnetic, DC-resistivity and magnetotelluric) survey was carried out by PMG (Centre for Mineral and Geological Resources) to investigate the geothermal manifestations in the Bora depression zone.

3. METHODOLOGY

The principal aim of the current study was to determine the variation in physical parameters that is associated with the heat source and attempt to delineate and characterize the geothermal reservoir, the deep structure that controls the flow of geothermal fluids and evaluate the geothermal resource potential in the Bora depression zone. In order to achieve these objectives, the present study involved utilization of integrated geophysical methods including gravity, geomagnetics and magnetotellurics measurements. Integrated methods are useful in the studies of geothermal resources since they complement each other and can therefore provide a detailed subsurface image that can be used for delineating geothermal reservoirs and mapping the associated heat sources. Standard gravity, geomagnetic and magnetotelluric techniques were utilized in the attempt to map the heat source, and to delineate, characterize and evaluate the geothermal reservoir/resource potential in the Bora depression zone. Figures 3 shows the gravity and geomagnetic station coverage while Figure 4 shows the magnetotelluric stations and profile lines in the Bora depression zone acquired for the purpose of this study.

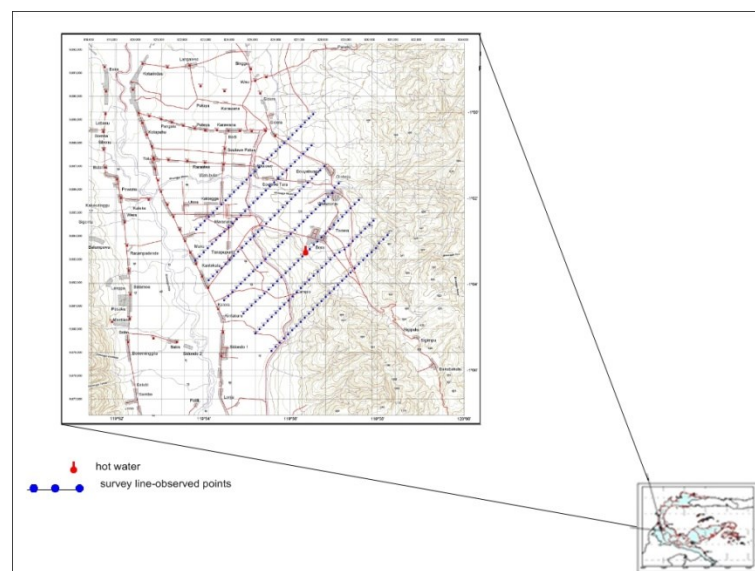


Figure 3: Gravity and geomagnetic stations coverage in the Bora survey area, PMG-B

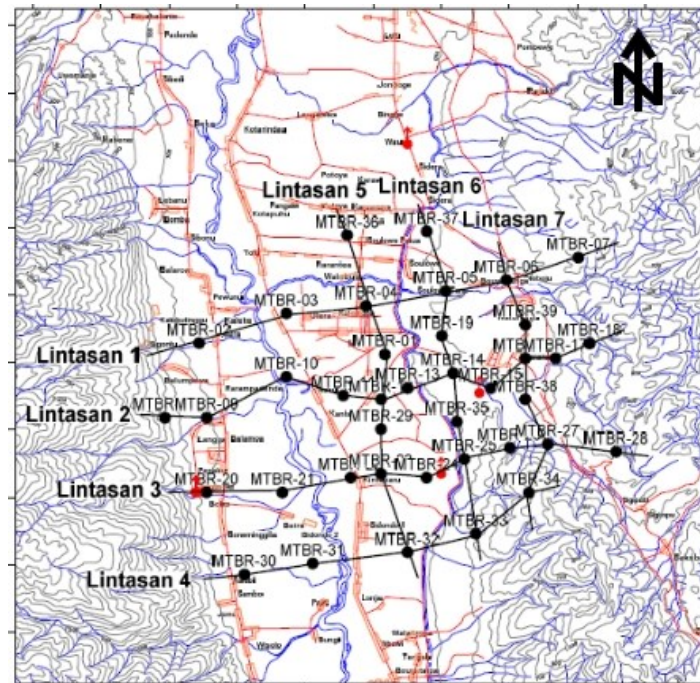


Figure 4: Magnetotelluric station coverage in the Bora survey area, PMG-C (note: lintasan-line, MTBR 03-MT station)

4. RESULTS

Gravity survey results (PMG-B) show a strong basin-like Bouguer anomaly trending N-S that supports the presence of the Palu-Koro fault. Relatively speaking, this anomaly is characterized by negative values (-2 to -7mgal) in the middle of the survey area, but flanked on both east and west side by high positive values (> 5 mgal) (Figure 5). The strong positive Bouguer anomaly in the eastern part of the study area, surrounds the Bora hot springs and is considered to be associated with intrusive rocks (granitic) as seen on the surface and hence considered to be the heat source of the Bora geothermal system. The presence of the Sidera fault is characterized by relatively small changes in lineation (nearly E-W) at the northern edge of the study area as seen in residual geomagnetic map in Figure 6. The fault controls the up flow associated with the Sidera geothermal manifestation. The Bora fault, on the other hand, is indicated by tight lineation in vicinity of the Bora geothermal manifestation with a direction close to NW-SE, as seen in the residual gravity anomaly map in Figure 5.

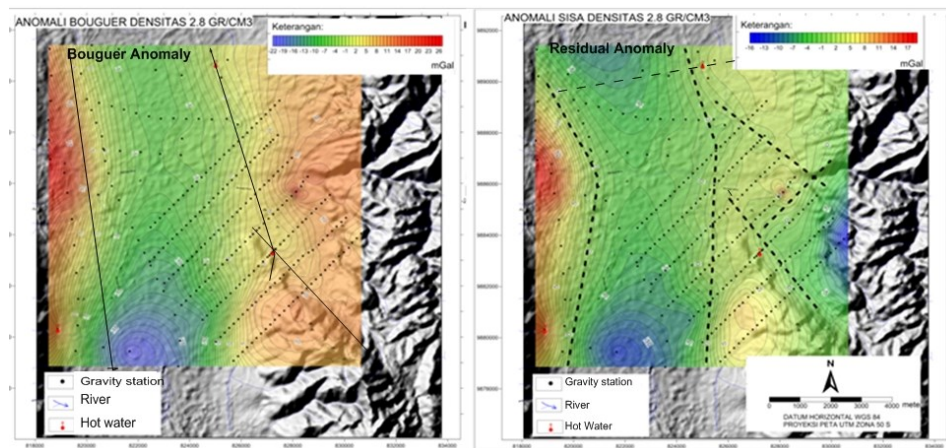


Figure 5: Bouguer and residual gravity anomaly map (modified from PMG-B, 2010)

Geomagnetic survey results, (Figure 6) also indicate the presence of Bora depression zone, characterized through negative low residual geomagnetic anomaly (> - 30 nT) in the middle of survey area (PMG-B). Relatively strong positive anomaly (> 20 nT) seen on the eastern side of the Bora geothermal manifestation is considered associated with intrusive rocks, as also indicated by the Bouguer gravity anomaly.

The results of MT data modeling is shown in Figure 7 (PMG-C). It shows two the resistivity variation along two profiles trending nearly E-W and N-S, respectively. These show three distinct layers in the Bora basin. At the top are thin layers of relatively low resistivity. Below this is a 500-1000 m thick layer, which has resistivities value of < 15 ohm-m. This layer is interpreted as altered rock and is considered to be cap rock for the geothermal system. The next layer is at least 1000 m thick and its resistivity value is < 150 ohm-m. This is interpreted to be fractured metamorphic basement rocks, with the fracturing resulting from the tectonic activity in the area. This layer probably hosts a steam reservoir where circulating fluids are heated by the underlying intrusive rocks that

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have a resistivity range of 150-200 ohm-m, which may be a part of the plutonic rocks that crop out on the eastern side of the Bora hot water manifestation.

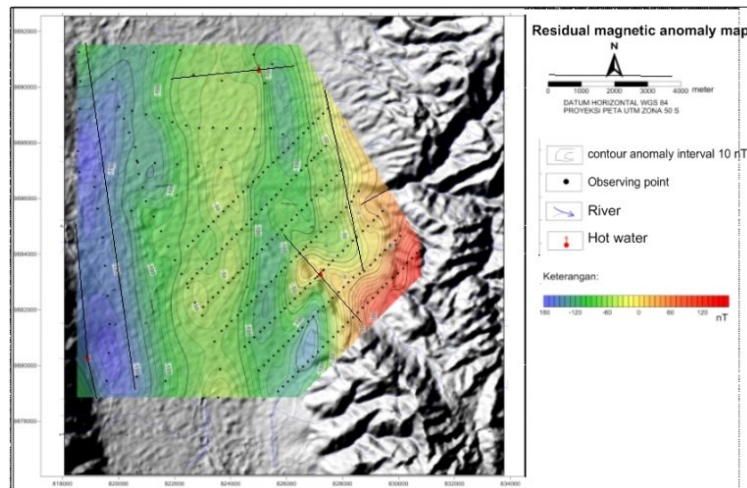


Figure 6: Residual magnetic anomaly map (modified from PMG-B, 2010)

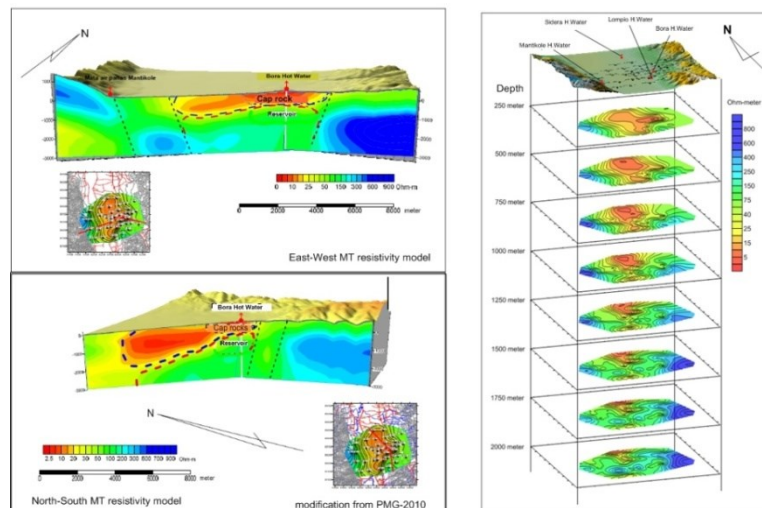


Figure 7: W-E and N-S resistivity cross-sections and stepwise resistivity maps based on MT measurements (modified from PMG-C, 2010)

Figure 8 shows a compilation of all the geophysical data from the Bora geothermal prospect area. Based on the survey, the size of the field is assessed to be approximately 80 km², with a production potential of >200 MWe.

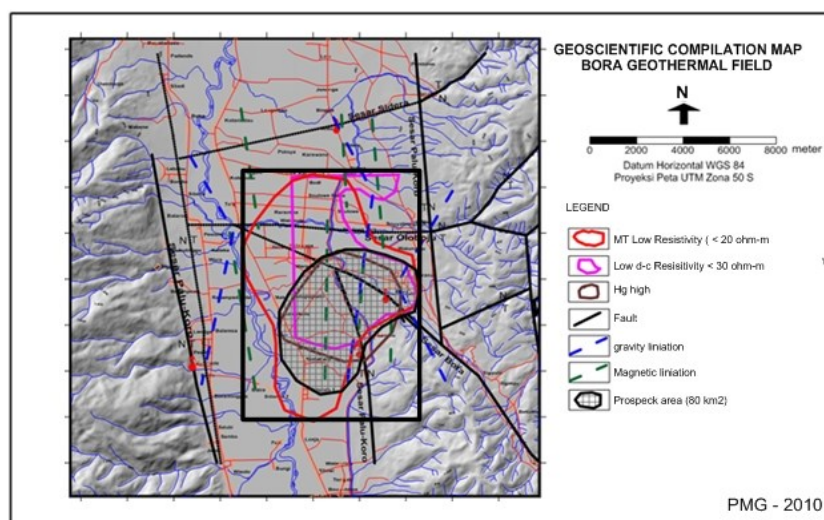


Figure 8: Map showing all geophysical data from the Bora geothermal field (modified from PMG-C 2010)

5. CONCLUSIONS

The presence of gravity and magnetic highs is evident in the Bora depression zone. The gravity and magnetic highs are characterized by an amplitude of > 5 mgal and > 20 nT, respectively, and are considered to be caused by the heat source for geothermal resource in the area. They are presumably explained by cooling intrusive due to plutonic intrusions. The geothermal system in the area is interpreted as a consequence of tectonic activity which was followed by an intrusive activity.

Two dimensional interpretation of MT resistivity data along E-W and N-S trending profiles indicates existence of three distinct layers, including cap rock, reservoir and heat source. The top of the reservoir is detected at the depth of > 800 - 1000 m and its thickness is assessed to more than 1700 m.

A compilation map, including geology, geochemistry and geophysics, shows that the geothermal prospect area is about 80 km^2 in size and is assumed to have a potential of approximately 200 MWe .

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