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**Review Article**

# GEOTHERMAL GRADIENT AND SUBSURFACE TEMPERATURE FOR ESTIMATION OF SOURCES, PATTERNS AND HEAT FLOW DIRECTIONS IN THE HYDROTHERMAL AREA OF MINAHASA INDONESIA

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**Abstract**
Geothermal gradient anomaly studies and subsurface temperature mapping play an important role in the estimation of heat flow sources and patterns, and also make a fundamental contribution in the field of geothermal physics, especially methods for geothermal energy exploration. The purpose of this study is to measure and mapping the temperature distribution in several subsurface layers in the manifestation of geothermal warm ground and steaming ground, and analyze the geothermal subsurface gradient, to determine the heat source zone, and the pattern and direction of heat flow from subsurface to surface in Hydrothermal area of Minahasa Indonesia. The method used is direct measurement in the field. To determine the coordinates of geothermal manifestations and location mapping, using remote sensing techniques. The results showed that the temperature gradient under the manifestation of geothermal energy increased with increasing depth. The pattern of heat flow in the warm ground manifestation is perpendicular from shallow depths to the surface, while the heat flow pattern under the steaming ground manifestation tends to spread towards the North-East.

**Keywords:** Geothermal Gradient; subsurface temperature; heat flow


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## INTRODUCTION

Geothermal gradients are caused by subsurface heat dissipation, which are not the same everywhere, and gradients vary from place to place due to differences in rocks and regional and local heat sources. In two places where the gradients in steady state are identical, the temperature at the given moderate depth will be different from the amount for which the average surface temperature is different (Lovering T.S. and H. D. Goode).

Direct method of estimating deep subsurface temperatures is by extrapolating measured gradients. However, if the depths of interest lie significantly below the depth for which temperature measurements are available, this extrapolation becomes uncertain, and variation in conductivity must be accounted for. When the thermal conductivity has not been measured or cannot be estimated with confidence, the temperature data should be from drill holes sufficiently deep that any changes in thermal conductivity between the bottom of the hole and the target depth will not be significant.


**Figure 1. The Study Area**

## LITERATURE REVIEW

The amount of heat (Q) flowing from the heat source to the surface depends on thermal conductivity (k), geothermal gradient (dT/dx) and the area: $Q = k\frac{dT}{dx}$ and if the gradient is constant through the interval x, $Q = kA(\frac{T_2-T_1}{x_2-x_1})$

where x is the depth parameter, T is temperature, $T_2>T_1$ and A is area.

If there is no other heat source between a given heat source and the surface, and no heat sink, the amount of heat transmitted when steady-state temperature conditions exist must be the same regardless of the differences in conductivity of the rocks:

$$k\left(\frac{\partial T}{\partial x}\right) = Q = k'(\frac{\partial T}{\partial x})'$$

$$\frac{k}{k'} = \frac{(\frac{dT}{dx})'}{(\frac{dT}{dx})}$$

and a geothermal gradient above a heat source will change in passing from one rock to another of different conductivity.

The main modes of heat transfer in the crust to the surface are convection and conduction. In mapping regional heat flow, an important goal is to separate out near surface processes, such as groundwater flow and hydrothermal circulation, from the deeper heat flow from the Earth's interior. Knowledge on the spatial variation in geothermal gradient and heat flow is of direct importance for the growing geothermal investigation and harnessing worldwide (Hjartarson, A., 2015). The temperature of rock or soil at and near the surface of the earth results almost entirely from heating by the sun and cooling through radiation, evaporation, and various heat-absorbing processes. At any particular surface location the heat supplied from below the surface is relatively constant; it represents heat from the interior locally supplemented by heat from subsurface oxidation or other local heat sources and is responsible for rock temperatures below the zone where the effect of surface temperatures is perceptible. The temperatures at a given depth in any locality, however, depend not only on the heat flow through the rocks but on the thermal properties of the rock, and on the surface temperature with which the subsurface temperatures are in equilibrium or to which they are adjusting (Lovering, T.S. and H. D. Goode, 1963). Joseph Forrest, J., et. al (2007) measurement Geothermal Gradients and Subsurface Temperatures in the Northern Gulf of Mexico. The result is a map that illustrates below-mudline (BML) depths to the 300-degree (BMLD300) subsurface isotherm throughout the northern Gulf. This map can be considered as a portrayal of subsurface temperature distribution, as the BMLD300 values are a direct reflection of thermal gradient, thermal conductivity, and heat flow. Nathenson, M. et al, briefly reviews heat flow and temperature gradients to provide a background for presentation of maps of heat flow and deep temperature gradients in the United States and of a table of thermal conductivities. These maps help to delineate areas favorable for the occurrence of low temperature geothermal resources and have been used to assign average temperature gradients for the estimation of reservoir temperatures for some geothermal systems. Masum, M (2014) describes the results of a gradient calculation method which applied to low-temperature geothermal field in SE Iceland. The aim of the study was to mapping geothermal gradient, low-temperature geothermal manifestations, as well as studying the site selection for production/exploration well drilling. A geothermal map is presented from which possible drilling targets for production and exploration are suggested. Sangin, S. et al (2018) uses results of temperature measurements in shallow boreholes to determine the geothermal gradients for a selected set of wells in Georgia. The hydrothermal flow in the Caucasus region driven by ongoing tectonic activities causes a varying temperature field that impedes determination of stable temperature gradients. Another method for geothermal gradient estimation is from singular log temperature as performed by Rodriguez, C. (2015). A database of “Geothermal Gradient and Heat Flow Data in and around Japan” is useful for modeling local and regional crustal thermal regime. New thermal data coupled with existing data help resolving horizontal heat flow gradients. Estimates of heat flow made by convolution of geothermal gradient data with thermal conductivities allow expansion of heat flow distribution (Tanaka, A. 2004).

**METHODOLOGY/MATERIALS**

Field data collection is separated based on the type of manifestation and adjusted according to the physical state of the manifestation. For the manifestations of steam ground, warm ground, and alteration rocks, the measured data are surface temperature and subsurface temperature at depths of 50 cm, 100 cm, 150 cm, and 200 cm, and also the area of manifestation.

Data processing using Excel and the surfer application. After the data obtained from field measurements is obtained, the next step is analysis to obtain subsurface temperature distribution data and temperature gradients. Data processing and analysis techniques can be seen in the flow chart in Figure 2.

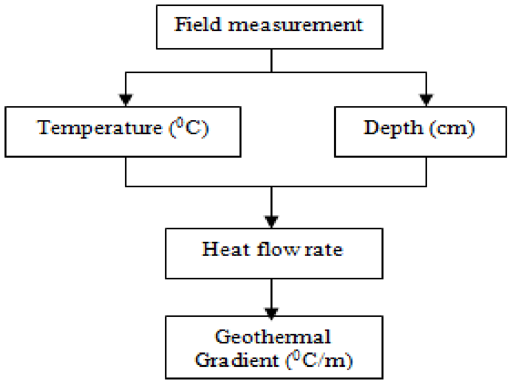


**Figure 2. Data processing flow diagram**

**RESULTS AND FINDINGS**

From 23 sample points, a geothermal gradient was obtained which varied between 13.62 to 75.5 $^0$C / m. At a depth of 200 cm the temperature reaches 102 $^0$C and the heat source comes from north-east and from the south. At a depth of 150 cm the temperature varies from 52 to 100 $^0$C with an even distribution in almost every direction. At a depth of 50 to 100 cm the maximum temperature reaches 98 $^0$C with heat propagation starting to concentrate then north-east, and then out to the surface in the north-east. The pattern of heat transmission is almost linear along with the geothermal gradient. The results of the calculation of the temperature gradient are shown in Figures 3 and 4. The distribution of surface and subsurface temperatures at depths of 50 to 200 cm is shown successively in figures 5 to 9.

**Table 1. Temperature and Depth**

| Depth (cm) | $T_{min}$ ($^0$C) | $T_{max}$ ($^0$C) | $\overline{T}$ ($^0$C) |
|---|---|---|---|
| 0 | 38 | 90 | 59.865217 |
| 50 | 42 | 98 | 71.817391 |
| 100 | 48 | 98 | 82.586957 |
| 150 | 52 | 100 | 87.652174 |
| 200 | 56 | 102 | 90.430435 |

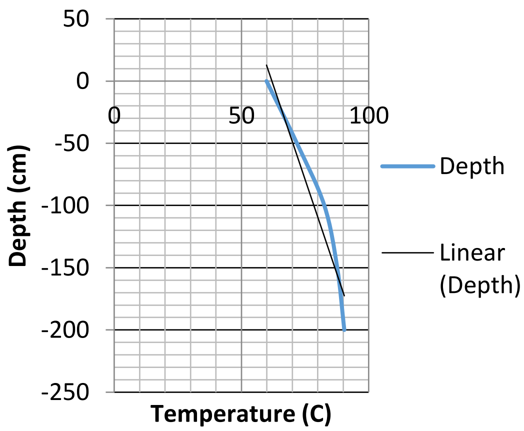


**Figure 3. Temperature graph with depth**

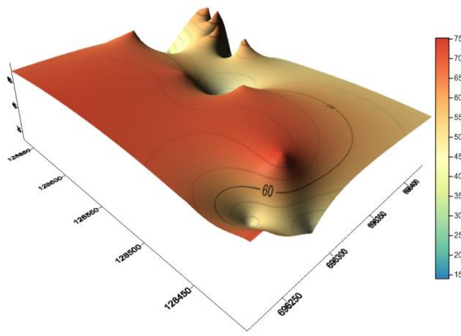

**Figure 4. Geothermal Gradient Contour Map**

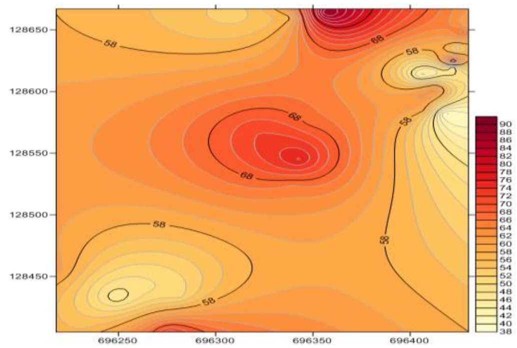

**Figure 5. Temperature at Surface**

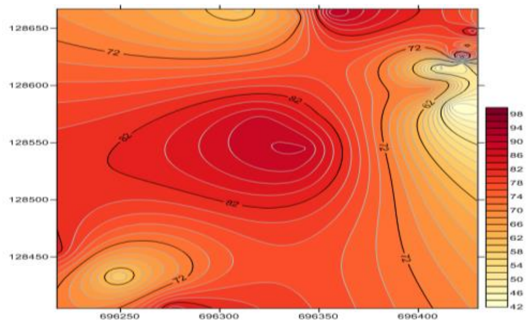

**Figure 6. Temperature at depth 50 cm**

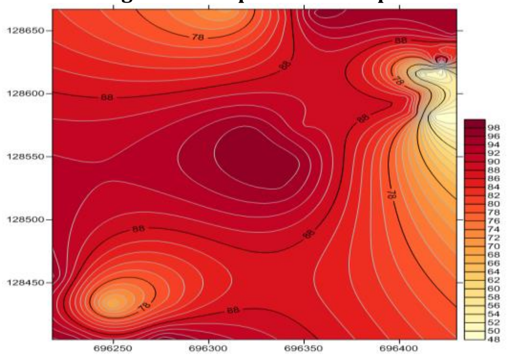

**Figure 7. Temperature at depth 100 cm**

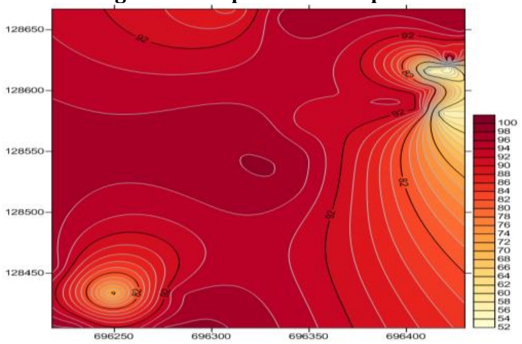

**Figure 8. Temperature at depth 150 cm**

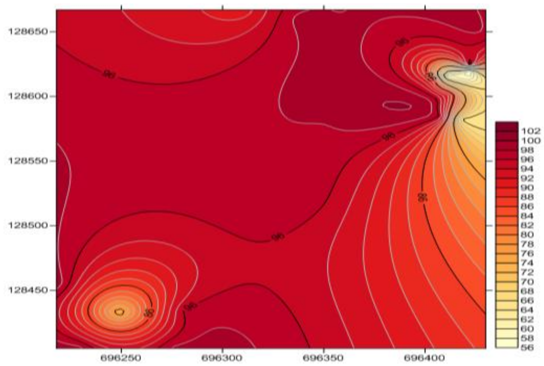

**Figure 9. Temperature at depth 200 cm**

**CONCLUSION**

Temperature gradients below the geothermal manifestation increase with increasing depth. The pattern of heat flow at the manifestation of warm ground is perpendicular from shallow depths to the surface. while the pattern of heat flow under the manifestation of steaming ground tends towards the Northeast. Geothermal Gradients in the Minahasa Hydrothermal Region vary between 13.62 to 75.5 0C / m. Subsurface Temperature increases with increasing depth. The heat source is estimated to come from the south. Whereas the pattern of heat flow to the surface is trending northeast.

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