3D Geological and Isothermal Model of Geothermal Field Based on the Integration of Geoscience and Well Data

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Abstract. The Conceptual Model in The Geothermal Field can illustrate subsurface conditions. A conceptual model is usually made in 2D however, the 2D model is generally limited to providing subsurface images, overcoming these limitations it is very important to use a 3D approach to improve understanding of subsurface conditions. 3D modeling needs to incorporate the integration of Geology, Geochemistry, Geophysics and Well Data studies. Visualization of the 3D model in this study was made using Leapfrog Geothermal software. The data used is data from the literature that has been previously published. The 3D model can provide a clearer picture of structural geometry and is effective in understanding geological features in Geothermal fields. 3D modeling can reduce uncertainty in drawing subsurface conditions, especially the geometry of Geothermal system components. The 3D model is also useful as a guide for determining make-up well in the future. More data is obtained, better models can be made. This model can be used as a guide in developing Geothermal fields in the future.

1. Introduction

The conceptual model of Geothermal systems is used to describe and illustrate the geological conditions and delineation of important processes that occur in a field related to temperature, pressure or fluid flow. Conceptual models of Geothermal systems are built based on an integrated study of Geoscientific with information about well testing and production data.

The key to the success of exploration is there is a clear perspective on the description of surface and subsurface conditions and understanding the characteristics of Geothermal systems in the area. The construction of a conceptual model must be updated as information increases. According to [1], Comprehensive conceptual models of geothermal systems should incorporate the following as far as available information allows:

- Provide an estimate of the size of a system, more specific information on the areal extent, thickness and depth range as well as external boundaries (vertical).
- Explain the nature of the heat source(s) for a system.
- Include information on the location and strength of the hot up-flow/recharge zones, including the likely origin of the fluid.
- Describe the location and strength of colder recharge zones.
- Define the general flow pattern in a system, both in the natural state and changes in the pattern induced by production.
• Define the temperature and pressure conditions in a system (i.e. initial thermodynamic conditions through formation temperature and pressure models).
• Indicate locations of two-phase zones, as well as steam-dominated zones.
• Describe locations of main permeable flow structures (faults, fractures, horizontal layers, etc.).
• Indicate the location of internal boundaries (vertical and/or horizontal) such as flow barriers.
• Delineate the cap-rock of the system (horizontal boundaries).
• Describe the division of the system into subsystems, or separate reservoirs, if they exist.

Not all Geothermal conceptual models incorporate all of the items above, in fact, only a few do so [1]. In general, conceptual modeling is built with a 2D model. The 2D model provides information in the form of a cross-section of the condition of the Geothermal area. However, there are limitations to the 2D model, which is less informative because there are limitations to reservoir geometry [2] [3]. A traditional 2D model have limitations and lack clear information in describing the overall geometry of the geothermal system and high temperature area. In contrast to 2D, 3D models can provide clearer and better understand a geothermal field. This 3D model can be updated as data increases.

3D modeling gives the ability to interpolate the geometry of a geological unit or structure at depth from scattered and varied data. 3D visualization of geological structures is an effective way to create an understanding of geological features [4]. Different models can be built to match the same data when in exploration stage and should be addressed when deciding the next step to de-risk development.

This paper discusses the development of a 3D geological model and isothermal model in the northeastern area of Soputan Mountain (Figure 1). The data used to construct this conceptual model is data from a published paper.

2. Method
To build a 3D model, integration of geoscience data and well data is carried out. This 3D model is processed using Leapfrog Geothermal software developed by Seequent (ARANZ Geo). Leapfrog Geothermal uses fast 3D interpolation to derive a continuous function from the data which is evaluated at any point in the model [5]. The 3D conceptual model built on this paper uses data from a published paper by [6]. The model is created by combining geological maps and cross-sections that are digitized using polyline (Figures 1 and 2).

![Geological map of the study area](image)

Figure 1. Geological map of the study area [6]
Figure 1 is a geological map that was made by Ganda and Sunaryo (as cited in [6]) and further detailed study of the structure was added by Siahaan (as cited in [6]). The geological studies divided the lithology into 7 different formations [6]; according to the oldest to youngest rocks they consist of:

- **Tondano Formation (Tt):** Interlayers of pyroclastic breccias, andesite lava, and tuff. These rocks carved the morphology on the southeastern part of the field. This lithology is the oldest unit in the field.
- **Tondano Tuff (Tf):** This unit comprises mainly tuff and pumice formed during the formation of the Tondano caldera. It can be compared to ignimbrite that formed during the erratic explosion of Tondano volcano.
- **Lengkoan Lava (Qlk):** Lengkoan mountain range is located on the northern side and consists mainly of andesite lava.
- **Rindengan 1 (Qrd1):** A series of interbedded layers of pyroclastic breccia, lapilli, tuff. This unit forms the flat morphology and covers most of the prospect area.
- **Rindengan 2 (Qrd2):** Interlayers of andesite lava and breccia; volcanic bomb and lapilli from proximal to the Rindengan mountain.
- **Sempu (Qsp):** Interbedded layers of pyroclastic breccias and andesite lava from Sempu volcanic center located in the south part of the map.
- **Tondano Lake deposit (Qal):** alluvium and lake deposit that consists of fine grain sandstone with a thin layer of tuff. These sediments occur in the vicinity of Lake Tondano on the eastern side of the map.

Figure 2 is a vertical cross-section that is used as a guide to create a subsurface 3D geological model. The information on subsurface temperatures derived from the downhole temperature from [7] to construct an isothermal model (Figure 3). Leapfrog uses a recently developed rapid 3D interpolation engine (FastRBF™) to construct 3D isothermal boundary from drill hole data and to solve geological modeling problems. This 3D isothermal model could then be used as an illustration of temperature distribution in the reservoir.

3. **Flow chart**

The workflow of building a 3D model is shown in Figure 4. The results of geoscience studies are inputted into Leapfrog Geothermal software. In Leapfrog Geothermal software a lithology model is arranged following the cross-section, then drawing a geometry reservoir, then modeling isothermal patterns based on downhole temperature data.

Figure 2. Cross-section of the study area [7]
Figure 3. (A) Temperature and pressure profiles LHD-26 and 30; (B) Temperature and pressure profiles LHD-27, 31, 33, 34; (C) LHD-32 and 35 [7]
4. Result and discussion
Based on exploration studies including temperature and pressure measurements. It was determined that the main Geothermal reservoir is located in the area around the well (Qrd2). The arrangement of the geological and isothermal models in Leapfrog is shown in Figures 5-9.

4.1. Geological model
Figure 5 shown geological map inputted into Leapfrog Geothermal. The surface of the model is digitized from the geological model using polyline tools, the results shown in Figure 6.

Lithology arrangement from the oldest to the youngest shown in Figure 7. Figure 7a shown volume of the Pre-Tondano (Tb), Figure 7b shown volume of the Tondano Tuff (Tt), Figure 7c shown volume of the Lengkoan (Qlk), Figure 7d-7f shown volume of the Rindengan 1-3 (Qrd1-3), Figure 7g and 7h shown volume of the Sempu 1 and 2 (Qsp1&2), Figure 7i shown volume of the Soputan (Qst), Final 3D geological model shown in Figure 7j.

4.2. Isothermal model
Figure 8 shown Isothermal Boundary which is the focus of the development area. Temperature profiles also show a distribution of high temperatures in the deep reservoir with the from temperature profiles there are indications of a shallow reservoir at 400 m depth. Temperature ranging between 240 and 260°C. Pressure profile data in Figure 3 show that this system is categorized as 2 phase fluid with water dominated. The estimated reservoir thickness is 400 m, from 1100 to 1500 m measured depth (1000-1400 m vertical depth) shown the highest temperature in Figure 9. All wells may be drilled to not reach the Soputan fault, which is thought to be a permeable structure.
Figure 5. Geological map inputted into Leapfrog

Figure 6. The surface of the geological model
Figure 7. The Lithology arrangement of the geological models
5. Conclusion
Conceptual models are an important basis of field development plans, i.e. in selecting locations and targets of wells to be drilled. The 3D conceptual model can help understand the elements of Geothermal systems better than 2D. A traditional 2D model have limitations and lack clear information in describing the overall geometry of the geothermal system and high temperature area. In contrast to 2D, 3D models can provide clearer and better understand a geothermal field. This 3D conceptual model can be updated as data increases. More data is obtained, better models can be made. Multiple models should be created based on different thinking and as more data is collected so this 3D model can be refined.
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References
[1] Axelsson G 2013 Conceptual models of geothermal systems-introduction Short Course on Conceptual Modelling of Geothermal Systems UNU-GTP
[2] Pratama A, Srigutomo W, Suryantini 2015 3D conceptual modeling based on geophysical and geological information for targeting geothermal prospect area in hidden geothermal system Proceeding Fourtieth Workshop on Geothermal Reservoir Engineering Standford
[3] Siahaan M N, Suryantini, Pratama A B 2016 3-D preliminary reservoir and isothermal models based on exploration data Proceeding 41st Workshop on Geothermal Reservoir Engineering. Stanford, California
[4] Milicich S D, Marcos A, van Dam, Rosenberg M D, Rae A J, and Bignall G 2010 Earth research 3-dimensional geological modelling of geothermal systems in New Zealand – a new visualisation tool Proceeding WGC 2010
[5] Alcaraz S A, Chambefort I, Pearson R, and Cantwell A 2015 An integrated approach to 3-D modelling to better understand geothermal reservoirs Proceeding WGC 2015
[6] Prasetyo I M, Sardiyanto, Koestono H, and Thamrin M H 2015 Clay alteration study from wells of Tompaso geothermal field, North Sulawesi, Indonesia Proceeding WGC 2015
[7] Handoko B T 2010 Resource assessment of Tompaso geothermal field, Indonesia UNU-GTP 2010 30