

3-D Preliminary Reservoir and Isothermal Models based on Exploration Data

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ABSTRACT

Interpretation of subsurface conditions is limited during the exploration stage. Integrated geoscientific data must be utilized in order to have a proper understanding about subsurface condition, especially for defining components of a geothermal system. This integrated description is usually conducted using 2-D model which is derived from cross-sections and maps. 2-D representation has limitation and less informative, since they cannot give detailed information about the reservoir's depth and volume. In order to have a better visualization quantification, and understanding of geothermal system, a 3-D model is considered as a more useful approach to represent the geothermal elements.

This paper presents tools and techniques for constructing 3-D preliminary geothermal reservoir and isothermal models, based on geoscientific data. The modeling procedure is carried out using Leapfrog Geothermal software. The first step to build an integrated model is to create geological model, based on interpretation of surface and structural mapping. Geological framework can give a better understanding of other geothermal elements. The 3-D isothermal model can be performed based on geochemical studies and gradient geothermal calculation. 3-D interpolation technique is used to generate interpolant models. The reservoir model then subsequently be represented using cross-section and maps. 3-D reservoir model extent are interpreted from conceptual model based on MT-derived resistivity, structural features, indication of up-flow manifestation features, then refined by isothermal model.

All these visualizations will help broaden the understanding of temperature distribution in the geothermal field and reduce the uncertainty of the interpretation of the subsurface condition. This results should then be useful as a guide for future determinations of exploration drill holes location.

1. INTRODUCTION

Analyzing and predicting the shape and geometry of a geothermal reservoir and subsurface conditions are critical elements during exploration stage. Geological, geochemical, and geophysical data must be well integrated in the construction of a reservoir's shape and geometry in the subsurface. This is quite tricky because of the limited availability of geoscientific data and each component of exploration has its own interpretation. The integration process also contains uncertainty and risks. In order to reduce them, the subsurface condition may need to be analyzed. So this procedure is necessary throughout the green field, to help many scientists to make decisions on the planning and development stages of the system (Axelsson & Mortensen, 2013). Therefore, there is a need for visualization of subsurface condition in order to aid in revealing the form and lateral extent of geothermal system's reservoir and the distribution of temperature in the subsurface.

2-D representations, such as maps and cross sections, are often used for visualizing a geothermal system. However, these types of visualization have limitations and are less informative, since they cannot give detailed information about the reservoir's depth and volume. 3-D models, however, will give a better perspective of geothermal reservoirs. Based on previous study of 3-D model which has been carried out by Pratama et. al (2015), 3-D model is reliable for constructing geothermal component in exploration stage. The extent of prospect area in subsurface gives more knowledge rather than 2-D model. The combination of multiple datasets using a single 3-D representation is important to give a broader perspective and better correlate available information. Moreover, this model can be used for further field development. In order to do this, the spatial relationship of all geoscientific data need to be represented. This paper uses Leapfrog Geothermal software in order to construct 3-D reservoir and isothermal models.

This paper discusses a methodology for the construction of reservoir and isothermal models. The input data used for the 3-D reservoir modeling procedure are geological interpretations and surface manifestation features, whereas the 3-D isothermal model is constructed from geothermometer-derived reservoir temperature, manifestation temperatures, and interpreted surface alteration. The generated 3-D reservoir and isothermal models were subsequently integrated to improve our understanding in geothermal system (Alcaraz & Moerkerk, 2012).

2. METHODS

2.1 Leapfrog Geothermal

Integration of multiple datasets using a single representation is important to have a better understanding of available information and improves a better correlation of geothermal elements. In particular, the reservoir and temperature distributions are better defined. The software used to generate the 3-D models is Leapfrog geothermal. Leapfrog Geothermal is a 3-D modelling and visualization software developed by ARANZ Geo in cooperation with GNS Science. This software is developed specifically for geothermal conditions

(Alcaraz, et al., 2011). All related datasets are inputs to the modeling procedure, including interpreted geological, geophysical and other parameters. These parameters are combined to construct reservoir model, then temperature distribution model.

2.2 Building a model

The general workflow of the model is described below (Figure 1). The geoscientific data (geology, geochemistry, and geophysics data) must be analyzed earlier to give parameters of the system modelling. In this paper, the paper is focused on system modelling as part of preliminary model.

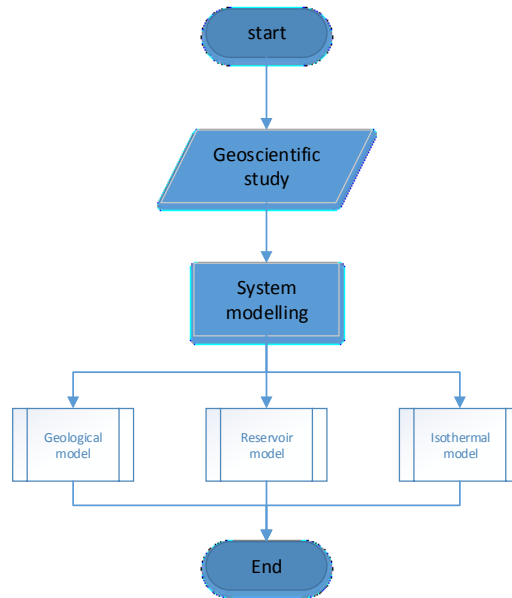


Figure 1 General workflow of 3-D model

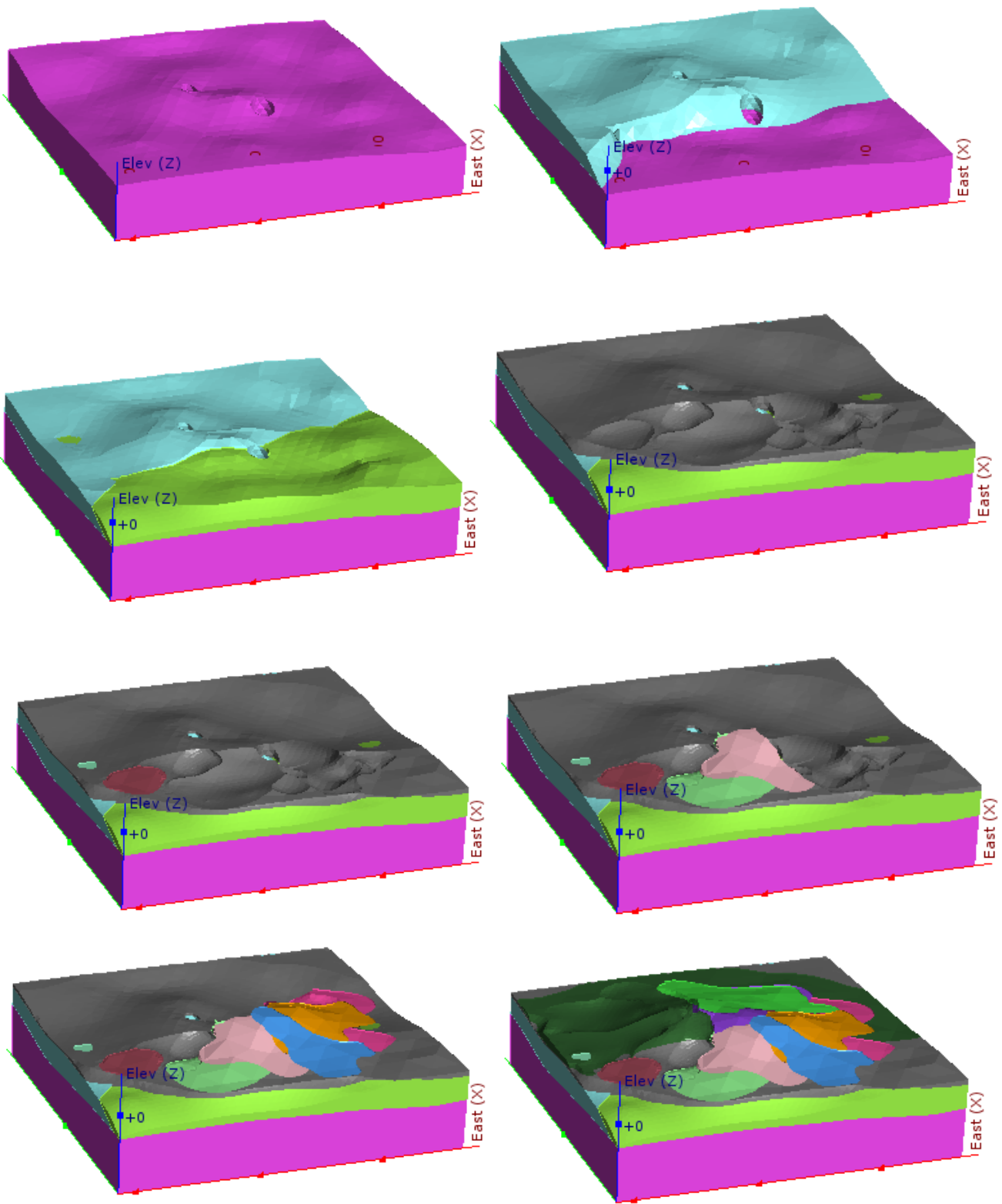
2.2.1 Surface data

In order to build a comprehensive model, the lateral extent of the model must be determined as well. In this case study, the upper border is defined by Digital Elevation Model (DEM) from SRTM data and the lower part of the border is defined as 2000 m.b.s.l. The side limit of the model is defined from Working Area. Surface geothermal features found in southern and northern part of study area consist of fumarole, steam vents, hot springs, and warm springs.

2.2.2 Subsurface data

Constructing geological model is the first step to build an integrated geothermal model because of data scarcity in the exploration stage (Alcaraz et. al., 2015). A geological model respectively shows the geological framework of geothermal system. The lateral extent, depth to each stratigraphy and faults based on field mapping and regional geology map can be defined by geological model. The geological model is also defined to explain reservoir lithology and the geographical extent of reservoir.

The sequence of subsurface geological model is constructed based on topographic map, geological section, and regional stratigraphy to constrain the boundary of the model both vertically and laterally. Topographic map must have Z information in order to adjust the model in the surface. Any geological cross-sections will be helpful to create a better visualization of subsurface condition. Stratigraphic cross-sections and synthetic boreholes must be made prior to the geological modeling procedure. The synthetic borehole comes from regional geological map. The synthetic boreholes contain all lithology in each depth and spread in all surface stratigraphy. The geological model will be more comprehensive if we use more synthetic borehole in each stratigraphy. Overall, there are sixty-four synthetic boreholes which is going to give extent of lithology.



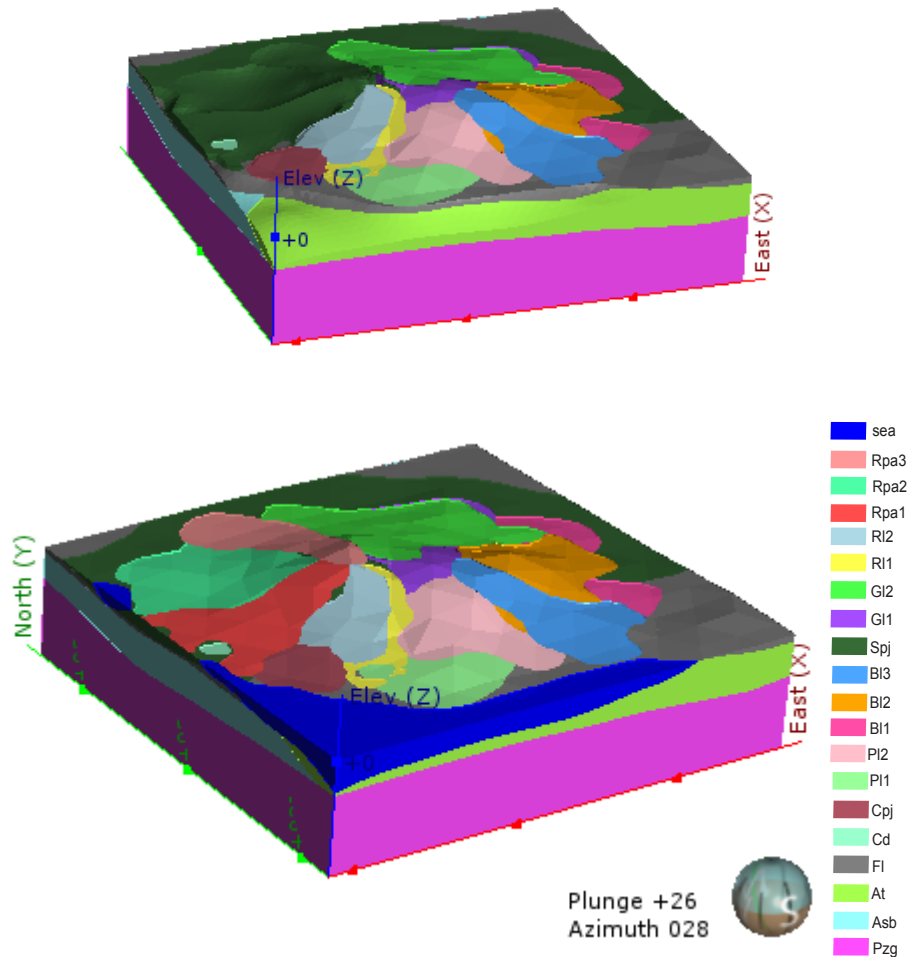


Figure 2 3-D stratigraphic model

Some formations are modeled in the modeling software as the “deposit type”, such as Pzg, At, and Asb to illustrate the deposition of geological formations. Pyroclastic fall type and tuff product, such as Fl and Spj, are modeled by classifying them into the “erosion type”. Using this type, a younger lithology will be formed and erode the underlying older layer. The rest of the formations, which are composed of pyroclastic flow and lava, are classified as “intrusive layer”. These are Pyroclastic Flow (Rpa1, Rpa2, Rpa3) and Andesite Lava (Rl1, Rl2, G11, G12, B11, B12, P11, P12) (Figure 2)

Fault traces and structural directions can also be imported to Leapfrog, by also including the dip and dip azimuth values in each fault. All fault parameters are derived from calculations based on the results of field mapping and complemented by information resulting from the analysis of remote sensing images. Fault structure, trending NW-SE, mostly categorized as strike-slip structures in this field.

3.2.2 Isothermal Model

The information on subsurface temperatures derived from geochemical studies and previous reservoir description from was used to construct isothermal model. Geothermometer and manifestations temperature are used to estimate geothermal gradient from surface to top of reservoir. For non-thermal and non-reservoir areas, since there are no well temperature data, a geothermal gradient of 4 °C/ 100 m (Hall, 1986) is assumed. Based on gas geothermometry, the reservoir is two-phase with a temperature of around 260-265 °C.

The method of Saputra et al. (2015), i.e. that uses synthetic wells and employs vertical temperature interpolation for each well, was subsequently adopted to estimate the subsurface temperatures based on the aforementioned information. The more synthetic wells are used, the more comprehensive model will be. The 3-D isothermal model is then constructed by linear interpolation of the calculated temperatures. Additional temperature information, which is interpreted as base of clay minerals, the presence of which were confirmed from the surface alteration, is also used to constrain the interpolation of subsurface temperatures. This 3-D isothermal model could then be used as an illustration of temperature distribution in the reservoir.

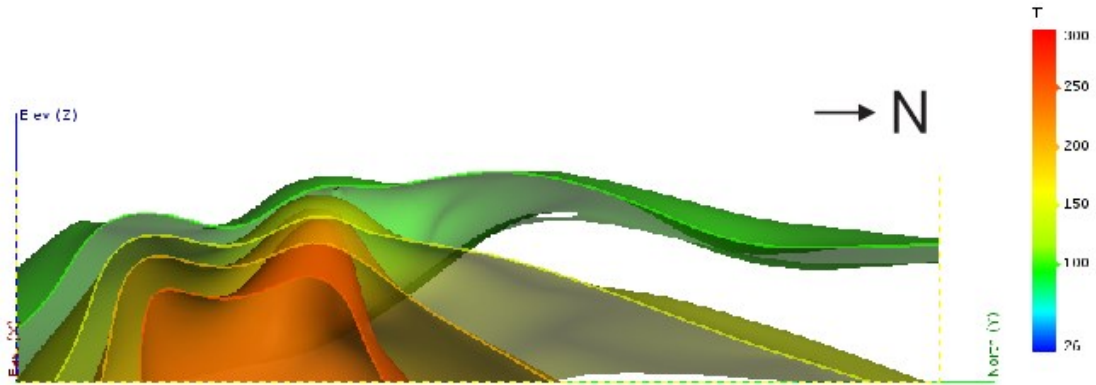


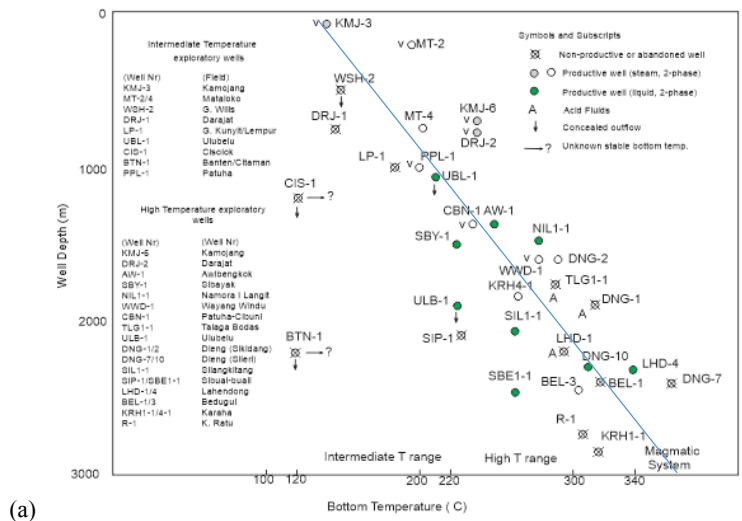
Figure 3 Isothermal Model

The depth to reservoir is also important to determine in constructing a model (Figure 4a). The reservoir depth is determined by a statistical model (linear regression) based on production temperature-reservoir depth plots of Hochstein and Sudarman (2008) in

Figure 4. For statistical model, based on reservoir temperature of 260 °C, this parameter is found to be at range 1500 to 1900 m depth, with a confidence level of 97% (Figure 4b). At each location on the surface that is beyond the area of surface manifestations, the determination of reservoir depth can also be guided by the depth to high-resistivity structure at that location.

3.2.3 Geothermal Potential

Reservoir model is considered to be important to use in deciding the exploratory drilling location as geothermal potential. Based on Grant and Bixley (2011), geothermal reservoir can be defined as the section of geothermal field which is hot and permeable, can be economically exploited for production of fluid and heat. There are various opinions on how to classify a geothermal reservoir based on its temperature. Hochstein and Browne (2000) consider a reservoir having a temperature of >225 °C to be “high temperature”; this definition is applicable in Indonesia. On the other hand, in the exploration stage permeability is determined by structural features and geophysical interpretations.



(a)

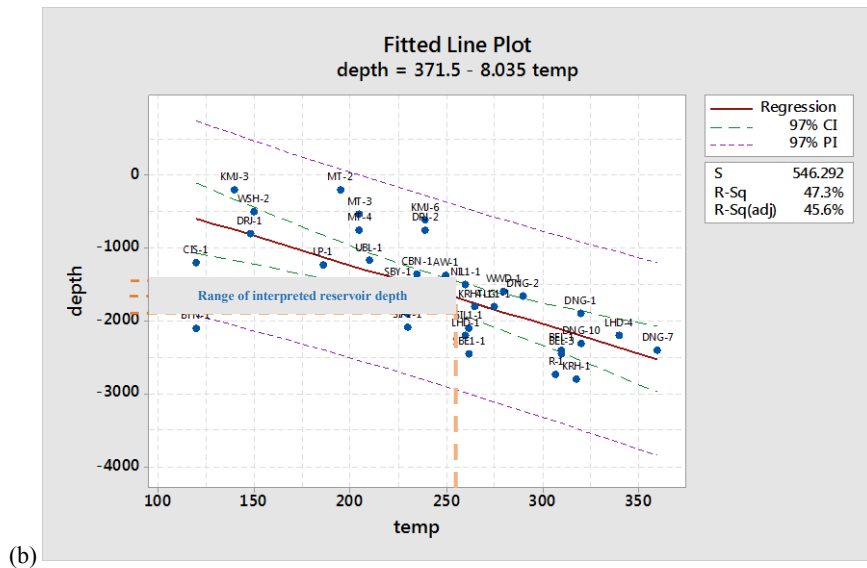


Figure 4 (a) temperature vs depth (Hochstein & Sudarman, 2008) ; (b) possibility range of reservoir depth from reservoir temperature

Assessment for the reservoir extent can be defined by intersection of interpreted high temperature, structural features and subsurface lithology. Low temperature in isothermal model below 180 °C can be interpreted as clay-cap (Reyes, 1998), found in southern area. The higher temperature below the interpreted clay-cap is assumed to be the reservoir area. The border of the reservoir is bounded by the structural features and indication of up-flow manifestation features. This interpretation is still in preliminary model, since the data is limited during exploration stage.

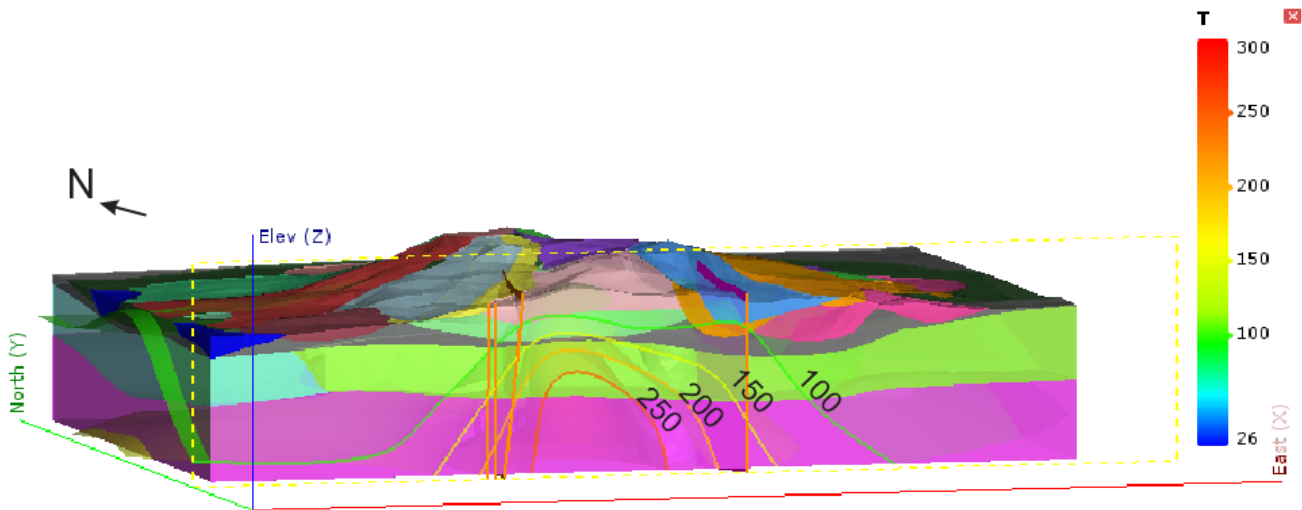


Figure 5 W-E cross section through geological model with isothermal model and fault traces

3. DISCUSSION

Promising geothermal potential in reservoir model and isothermal in early stage of exploration can be constructed in order to give a broader understanding about geothermal system. 3-D interface will help to understand the geothermal element better than 2-D visualization. The more geoscientific data are collected, the more comprehensive model will be.

3-D geological model can be used to define the potential area for geothermal purpose, since this gives better point of view of geothermal stratigraphy. Geological interpretation from surface mapping and structural mapping allow us to visualize subsurface geology in this field. Opening crater, structural network, and stratigraphy become basic framework to understand geothermal system. In this model, the F2, F6, F12, F25 in the southern area become the border of the reservoir model since it closes to the southern crater and high

temperature manifestations which indicated as permeable structures. Lithology contact of stratigraphy is a part of permeable zone indication. As we can see in Figure 5, the vertical contact between two lithology and high temperature on isothermal model can be determined as promising area of geothermal potential.

The reservoir is defined below the southern area. For the isothermal model, a high temperature zone (260 °C) is located beneath the southern area. The integrated reservoir and isothermal model forms the reservoir with more information and extent. Based on Hochstein and Browne (2000), that high temperature reservoir has temperature >225 °C, then the depth of actual reservoir will be shallower than the model.

The integration of the appearance of interpreted clay-cap, structural and up-flow manifestation features can be used to interpret the border of reservoir. The lithology contact of andesite lava and pyroclastic fall can be considered as permeable zones which are located in reservoir area. The potential of geothermal existence confirmed by all data above. However, this model is still categorized as preliminary model, since there is no exploration well yet in study area. The aim of creating 3-D model is to know how exploration stage can lead into knowledge of geothermal elements in 3-D.

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