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GEOPHYSICAL FIELD MAPPING

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ABSTRACT

Geophysics is the study of the earth by the quantitative observation of its physical properties. In geothermal geophysics, we measure the various parameters connected to geological structure and properties of geothermal systems. Geophysical field mapping is the process of selecting an area of interest and identifying all the geophysical aspects of the area with the purpose of preparing a detailed geophysical report. The objective of geophysical field work is to understand all physical parameters of a geothermal field and be able to relate them with geological phenomena and come up with plausible inferences about the system. Four phases are involved and include planning/desktop studies, reconnaissance, actual data acquisition and report writing. Equipments must be prepared and calibrated well. Geophysical results should be processed, analysed and presented in the appropriate form. A detailed geophysical report should be compiled. This paper presents the reader with an overview of how to carry out geophysical mapping in a geothermal field.

1. INTRODUCTION

Geophysics is the study of the earth by the quantitative observation of its physical properties. In geothermal geophysics, we measure the various parameters connected to geological structure and properties of geothermal systems. In lay man's language, geophysics is all about x-raying the earth and involves sending signals into the earth and monitoring the outcome or monitoring natural signals from the earth. Geophysical field mapping is the process of selecting an area of interest and identifying all the geophysical aspects of the area with the purpose of preparing a detailed geophysical report. Before any survey is undertaken, objectives of the study must be well defined and attainable. Since there exist numerous geophysical methods, the geophysicist must be able to choose methods that will be applicable in the area, cost effective and be able to give solution to the problem at hand. There are various reasons why we carry out geophysical surveys and they include: prospecting for geothermal resources, mineral resources (metallic and non-metallic), petroleum and gas, water resources (surface and ground water), geo-hazard assessment (volcanic, seismic), engineering foundation design (geotechnical) and environmental issues.

In geothermal geophysics, we measure the various parameters connected to geological structure and properties of geothermal systems (Hersir and Björnsson, 1991). A geothermal system is made up of four main elements namely, a heat source, a reservoir, fluid which is the carrier that transfers the heat and fluid path ways (e.g. faults and fractures). Parameters that characterise a geothermal system are temperature, porosity, permeability and chemical composition of the fluid. Our interest is in areas where we get high temperatures, high pressure, high porosity and good permeability and low content of dissolved solids and gases in the water.

1.1 Objectives

A study area is selected to answer specific geophysical questions based on literature review or specific interests. The main objectives for carrying out geophysical surveys in geothermal areas are:

- To detect and delineate geothermal resources;
- To identify and locate exploitable reservoirs;
- Estimate geophysical properties of the geothermal system; and
- To get a conceptual model that will assist in siting of the drill holes through which hot fluids at depth will be exploited.

2. GEOPHYSICAL METHODS

A wide range of geophysical surveying methods exists for exploration for geothermal energy as well as the monitoring of geothermal reservoirs under exploitation (Ndombi, 1981; Mariita, 1995; Simiyu and Keller, 1997). The type of physical property to which a method is sensitive to assists in deciding the method to be used in a particular survey depending on the outlined objectives. Geophysical method can be divided into the following two categories:

- Direct exploration methods **-** These are methods where the variation in physical properties is directly related to the geothermal system (e.g. temperature). They include thermal and electrical methods (DC and AC methods).

- Indirect exploration methods – In these methods, physical properties investigated do not directly relate to the geothermal system. An anomaly is caused by associated geological formations or structures (e.g. fault, dykes). They include structural methods (gravity, magnetic and seismic).

2.1 Main geophysical methods

Geophysical methods play a significant role in the investigation of geothermal prospects because they are the only means to finding deep subsurface structures at much lower costs than the most direct method, drilling. A relatively wide area can be surveyed within a short time using geophysical techniques although the methods are sometimes prone to major ambiguities in data interpretation. Geophysical surveying does not overrule the need for drilling but, if properly applied, it can optimise exploration programs by maximizing the rate of ground coverage and minimizing the drilling requirement.

The main geophysical methods applied in geothermal exploration are:

- Thermal methods (soil temperature, heat flow);
- Electrical methods (resistivity, self-potential);
- Gravity method (rock density);
- Magnetic method (rock magnetization); and
- Seismic methods – passive method (wave velocity, seismicity, geological structures).

It should be noted that there is no superior method thus integration of different geophysical techniques can be effective in mapping defined structures in tectonic regimes where geothermal resources can be found. However, electrical and electromagnetic methods are commonly applied in geothermal exploration. A geophysicist should carefully choose methods to be applied bearing in mind there are different methods for low and high temperature systems.

3. PHASES OF GEOPHYSICAL FIELD MAPPING

Geophysical projects are implemented in four phases that are interrelated and important. They include desktop studies/planning, field reconnaissance, data acquisition and report compilation.

3.1 Desktop studies / planning

This phase of mapping is mostly carried out in the office. It involves identifying a field study and outlining objectives of the field survey and then planning how field work is to be done. Once the field is identified, the geophysicists compile all existing and relevant information on the field which includes literature review and map compilation. This is done to avoid duplication of work and most importantly simplify a field study by being more organised. A field plan is then drawn up which outlines how field work will be carried out in terms of number of personnel, duration of work, methods to be applied and resources needed. When preparing the field programme, various factors should be considered since they impact on the quality and quantity of data collected. They include, kind of survey applicable, availability of personnel, funds available, weather, objectives of the study and output required. It's advisable to carry out field surveys during favourable weather e.g. during dry seasons in tropical countries and during summer or fall in colder countries.

Resources such as maps (topographical, base maps), data and existing geological and geophysical reports are obtained and reviewed. A field budget must also be prepared that details costs involved such as fuel, consumables, casual /guards hire, number of personnel and their allowances and miscellaneous costs. Official approval by the government or institution must be obtained. Equipments to be used should be identified and arranged, calibrated and tested prior to the field work.

3.2 Reconnaissance

This phase of mapping is carried out in the field and aims at ensuring the area is suitable for the planned study. It involves assessing the road network and ensuring the area is accessible. Where to store the equipments and charge them should also be identified during this phase. Casual workers / guards availability, weather patterns, fauna and flora in the area (e.g. buffalos in a park) and security issues should be looked at. Since geothermal resources occur mostly in traditionally important or protected areas, it's important to dialogue with the local community and obtain approval from them to carry out the study. This ensures lack of hostility and cooperation by the locals. It is prudent to involve the local community since they understand their environment better than yourself and can pinpoint areas that maybe of interest. They also may give you a historical background of the area.

3.3 Data acquisition

This phase aims at acquiring good geophysical data. It follows field reconnaissance and takes up more time than the other phases. For a successful survey, data should be acquired properly and in an organised manner. The field crew must be fully equipped with all the necessary tools, be physically psyched and mentally prepared to collect good data. Data may be digital or analogue. Accuracy while taking measurements and setting parameters in the equipments should be emphasized at all times. Remember, garbage in, garbage out. Data should be well recorded and entered in a field book which ought to be water resistant. Remember to detail and write more than less using illustrations and sketches. Geological features, power sources, topography, location of measurements, date, time, equipments used, station number and name of operator must be well recorded in an organised and legible manner. It is a good practice to always view your data in the field and judge the quality and quantity of the data and repeat if necessary. This saves time and money. Copies of data and field book should be made. Above all, the field crew should work as a team for better results.

3.4 Report compilation

This phase ensures that a good detailed geophysical report is prepared. It involves reporting results obtained after data acquisition, processing and interpretation. It is the final stage in the survey and is done at the office. It is also the most challenging stage where keenness is extremely important.

The general problem in geophysical surveying is the ambiguity in data interpretation of the subsurface geology. This arises because many different geologic configurations could reproduce similar observed measurements (Dobrin and Savit, 1988). This basic limitation is brought about from the unavoidable fact that geophysical surveying attempts to solve a difficult inverse problem. In spite of this limitation, we can rely on geophysical data. During data interpretation process, it is crucial to have group discussions with all those involved in the actual fieldwork and those with field experiences form other scientific field.

Geophysical report should be detailed, legible, concise and informative. It should highlight location of anomalies and phenomenon causing the anomaly. The report should contain at least the following chapters:

- Introduction – introduce the work undertaken, including location, objectives and climate.
- Geological setting – give a brief description of the geological setting of the area including stratigraphy and structural setting.
- Previous work – describe previous work done in the area and what were the conclusions and recommendations.
- Methodology – Describe the methods used during the fieldwork.
- Results – present your results and include maps.
- Discussion – Discuss your results and interpret them in terms of what they mean and represent. Some knowledge on geology is needed.
- Conclusions and recommendations – Give your conclusions and recommendations in this section.

It is advisable if you have some maps and cross sections include them in the appendix.

4. EQUIPMENTS AND TOOLS USED DURING FIELD WORK

Several equiopment and tools and their accessories should be carried when carrying out a geophysical survey. The kind of equipments to carry is determined by the purpose of survey and methods used. This section will discuss common equipments and tools used during geophysical surveys in geothermal fields.

1. **Maps –** As mentioned earlier, maps are collected during the planning stage. Maps that are of much help to a geophysicist include base,topographic and road network maps. It is important to note the scale of maps depending on the aerial extent of the survey area.
2. **Field notebook and pens –** All important observations must be written down in a concise, organised and legible manner. The fieldnote book should be hardcover, water resistant and not so big. Pens and pensils are a must have.
3. **Compass –** A compass is used for determining direction. It is important when carrying out all geophysical methods. It can also be used to determine strike directions and dip of fault planes.
4. **Hand held GPS (Geographic positioning system)** – This is a satellite based navigation system comprising three basic parts, the satellites in space, monitoring stations on earth and the GPS receivers. Although most geophysical equipments have inbuilt GPS systems, it is

advisable to always have a hand held one. This equipments is for finding and storing station location, tracking paths used, measuring elevation and helping one locate stations in the field.

5. **Field camera** – It is important as it stores visual memories/evidences of the field work. It is very important to take photographs of all interesting features ensuring a scale is used in each instance, video clips can also be of use. One must also remember to take a GPS reading for each photograph taken. Photographs are important for descriptive purposes especially during report writing and for making presentations.
6. **Safety gadgets and first aid kit –** Safety clothing protects you from harsh field conditions. They include sturdy shoes, clothes that are tough in fabric preferably jeans or khaki, hat and sunglasses to protect one from the sun, a backpack plus a raincoat and wellington boots just in case of wet environments. Safety clothing should aid one to be more effective by being comfortable and safe at the same time. First aid kit should be fully equipped.
7. **Batteries, battery chargers and solar systems** – One should make sure that either size D or 12V batteries are availed. Battery chargers are used to recharge the batteries while in the field. Solar panels are used in remote areas where there is no power source to charge the batteries.
8. **Masking tape/ leveling spirit –** Masking tape is used to hold various things together e.g. cables and mark them. Levelling spirit is useful especially when carrying out magnetotelluric (MT) and audio magnetotelluric (AMT) surveys. It ensures that the magnetic coils are well levelled.
9. **Hoe and Auger bit –** Used to make holes for the electrodes and vertical magnetic coils respectively During MT/AMT surveys.
10. **Field laptop –** Used for downloading data from the equiopment and also pre-processing data while in the field.
11. **Geophysical equiopment** – These include equiopment used in geophysics for different surveys. When carrying out a geophysical survey, the choice of equipments to use is dependent on the purpose of the study. Several equiopment can be carried for a one field survey. These equiopment are:

    a. Magnetometers;
    b. Gravimeters;
    c. Seismometers and data loggers;
    d. Thermal methods tools;
    e. Transient electromagnetic equipments (TEM);
    f. Magnetotelluric equipments (MT);
    g. Audio magnetotelluric equipments (AMT); and
    h. DC method equipments.

5. GEOPHYSICAL DATA PRESENTATION

Once geophysical data is acquired, a geophysicist is at task to present the results in a manner that a non- specialist will understand. A series of data manipulation techniques can be applied to the data to remove errors and 'noise'. This data can be in three forms:

- Raw data – these are measurements directly from the instrument and contains background effects and errors. The specialists evaluate the accuracy of the data, edits and corrects it and does further processing. Data in this form is useful to the specialist only.
- Reduced/corrected data - this is data that have been processed to get rid of errors and various non relevant components. E.g. getting rid of power line effect in data and performing terrain corrections.
- Interpreted or modelled results – These are results derived by model calculation from data and depicts actual models of the subsurface. At this stage, the abstract or indirect data is converted into maps of specific physical characteristics of sub-surface rock formations. For example, a

model of actual resistivity distribution (1D, 2D, 3D) derived from apparent resistivity curves. This is the final product that a geophysicist produces and is useful even to the non-specialist.

Data processing, analysis and interpretation is a challenging stage as one has to be quite keen and have some knowledge on data handling. After the field data is corrected if necessary, converted to appropriate units, modelled and interpreted, it is then presented to the user in a pictorial manner. It can be presented as:

1. Graphs – data graphs commonly show measurements as a function of distance, time or frequency.

2. Iso anomaly curves – these maps give an overview of the results but not all the details (Figure 1). Iso- resistivity maps are plotted at particular depths and show resistivity patterns at that depth. They are summaries of the observations and not geological interpretations.

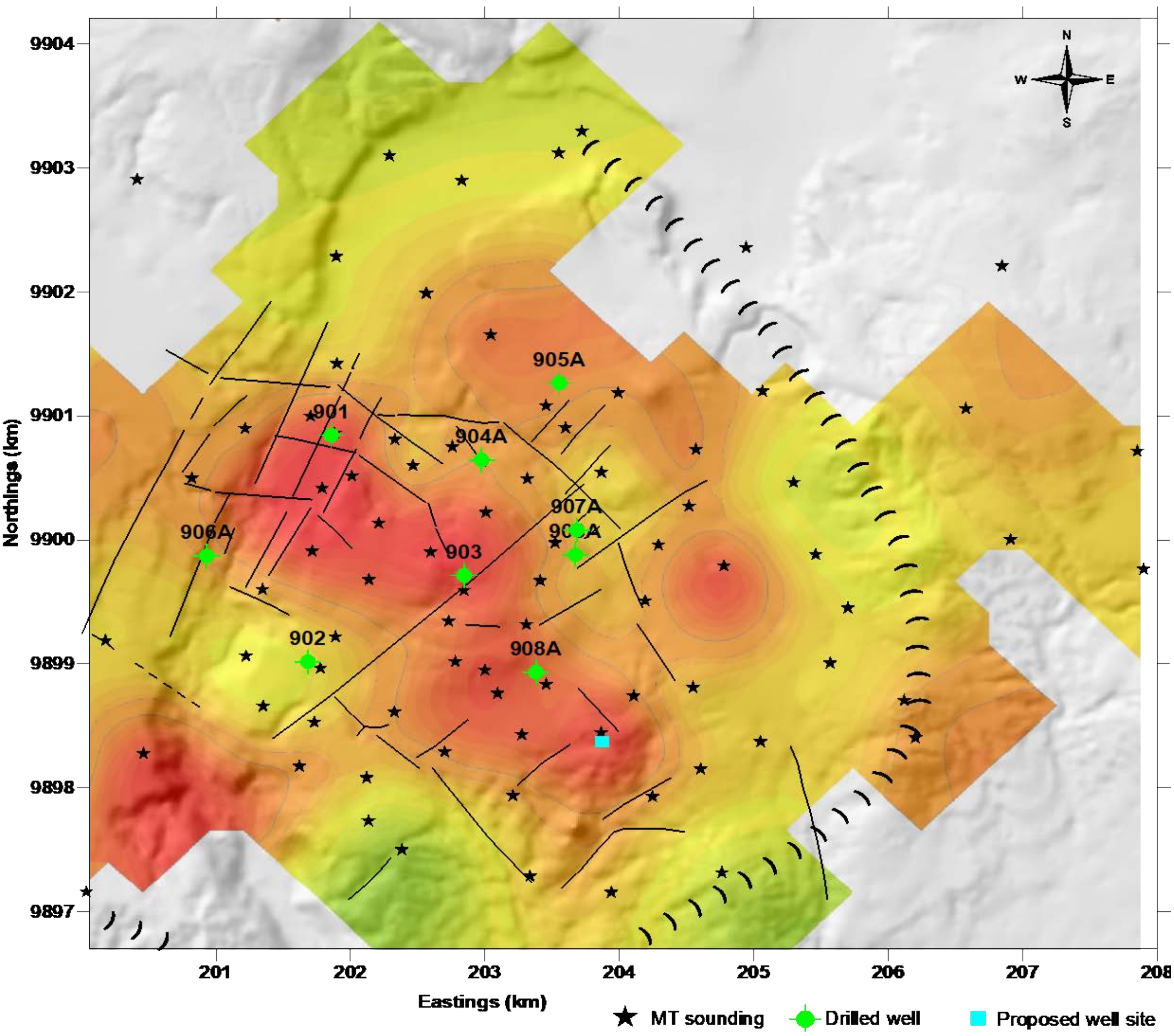

FIGURE 1: MT resistivity iso anomaly map at 700 masl of Domes area

3. Contour maps (Figure 2).

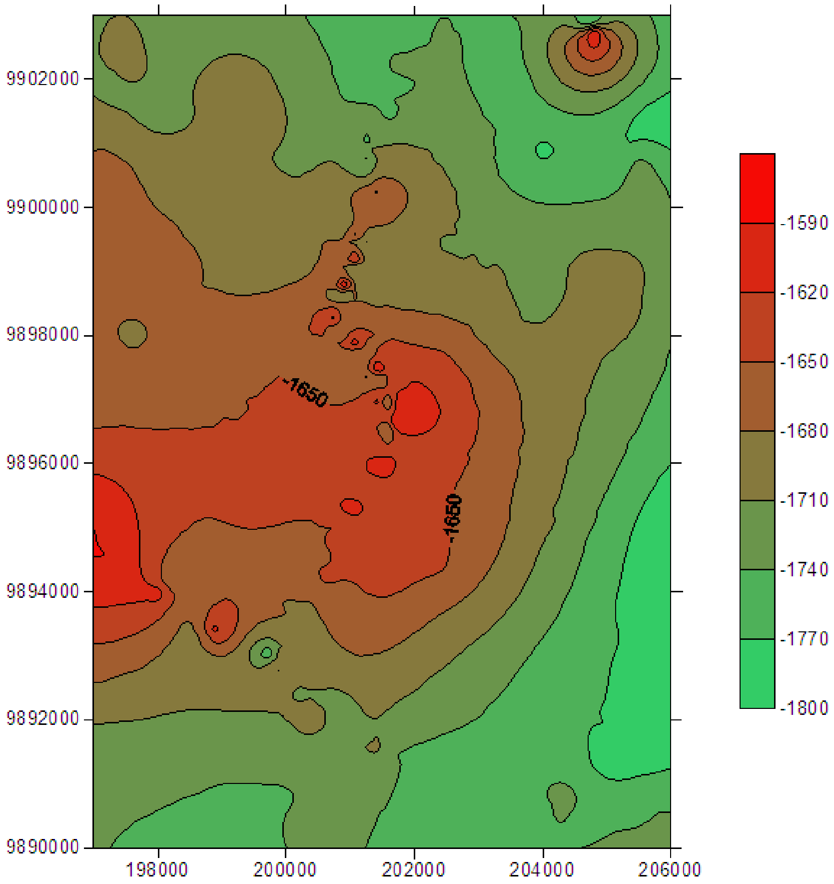

FIGURE 2: Gravity contour map of Longonot, Suswa and Olkaria showing the variation of the gravity anomalies in the area

4. Cross sections (Figure 3).

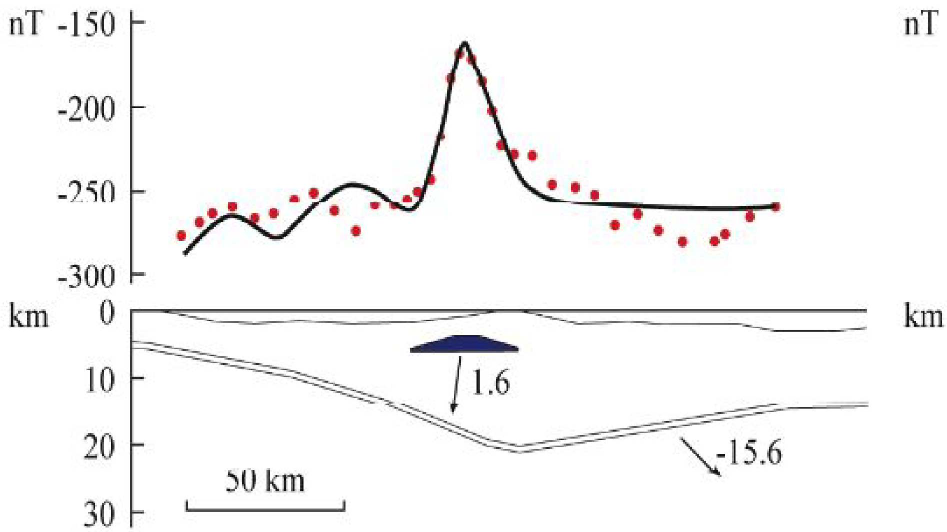

FIGURE 3: A cross section showing a 2D body modelled to fit the observed magnetic field anomaly. The red dots show observed field while the black line show the calculated field.

5. Profiles or pseudo sections – profiles visualize continuous variation of the anomaly better than contour maps (Figure 4).

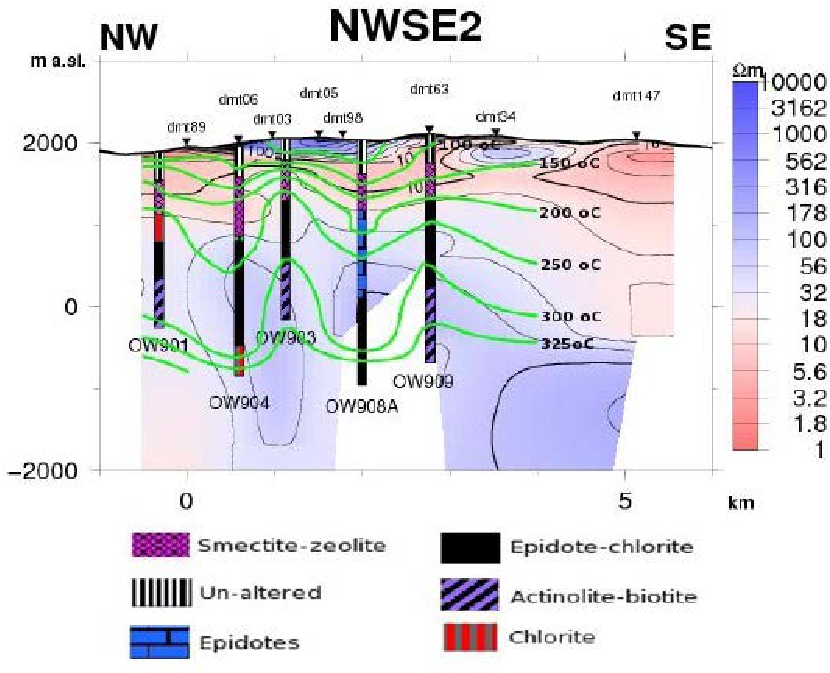

FIGURE 4: MT resistivity profile map across NW to SE in domes.
Resistivity varies laterally and vertically.

6. 2/3 dimensional maps (Figure 5).

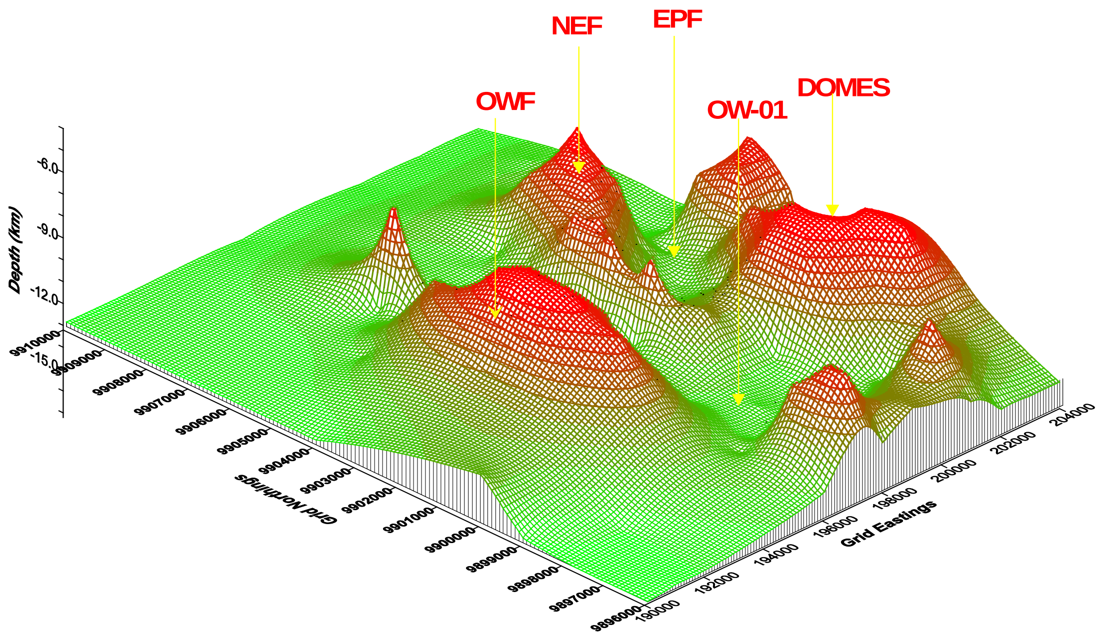

FIGURE 5: 3D plot of depth to attenuating heat sources (fluidized) beneath Olkaria area

6. CONCLUSIONS

In conclusion, geophysical mapping is paramount to geothermal exploration. As mentioned earlier, no single discipline supersedes the rest. Results from other disciplines should be regarded with greatest respect (and distrust). Each discipline should develop individual ideas about the geothermal field and when all the different data sets are in place, they must be interpreted jointly to synthesize a conceptual model which is consistent with all the data from different disciplines. The conceptual model is then used to site exploration wells.

It is essential to work as a team not only to complement individual capabilities but also create synergy for effectiveness and efficiency. Proper planning is pertinent to the overall success of the project. It's crucial that one adheres to the budget. Geophysical equipments are generally expensive and utmost care should be exercised when handling them. Accuracy during data acquisition is of great importance as repeating a measurement is expensive and should be done only when very necessary.

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