OVERVIEW OF GEOTHERMAL SURFACE EXPLORATION METHODS

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Abstract

The recent increase in conventional fuel prices has resulted in an increase in the interest innatural sources of energy such as geothermal energy. Geothermal energy is the vast reservoir of heat energy in the earth's interior , whose surface manifestation are volcanoes, fumaroles, geysers, streaming grounds and hot springs. The exploration of geothermal resource in India is in nascent stage and that motivated to look into the aspect in detail. Commercial exploitation for generation of electricity is yet to take place in India. The scientific disciplines commonly involved are geology, geochemistry, and geophysics. This paper shows various techniques which are used for exploration of geothermal energy in Indian context, which preliminarily deals with hot springs, as there are no major active volcanoes or other surface manifestations present in India. Initially, it focuses on primary geological studies like remote sensing and geochemical analysis of water from hot springs to delineate prospective zones. After short listing prospective geothermal sites, geophysical methods such as magnetotellurics, gravity, magnetic and seismic methods are used. The entire exploration method is analogous to oil and gas exploration where the practice is to narrow down the sites based on the probability of success. It emphasizes on accuracy of surface exploration methods so that the risk can be minimized while practicing subsurface exploration methods such as drilling which requires huge capital investment.

KEYWORDS: *Geothermal, exploration, geophysical techniques, Seismic survey, Geochemical study, Remote Sensising, Gravity, Magnetotelluric, resistivitiy, Magnetics.*

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1. Introduction

Geological and Geophysical methods are the two most important branches to explore geotheral and hydrocarbon resources. Geophysical exploration deals with measurement of the physical properties of the earth. The main focus is on parameters that are sensitive to the subsurface temperature and fluid content of the rocks. The objective of the exploration is to get the maximum amount of information about the properties of the geothermal system (Georgsson, 2009).

The aim is to:

- Delineate a geothermal resource.
- Outline a production field for geothermal system
- Locate aquifers

- Assess the general properties of the geothermal system
- Characterize thermal fluids
- Define geometry of the geo-bodies
- Develop a conceptual model
- Locate the suitable drilling targets
- Identify area with potential geothermal energy.

The important physical parameters/properties of a geothermal system are as follows:

- Temperature
- Porosity
- Permeability
- Chemical composition of fluid
- Pore Pressure
- Flow rate
- Water Saturation

Above parameters cannot be measured directly through conventional geophysical methods. But there are some other parameters that can be measured are linked with the parameters mentioned above and may give important information related to geothermal system (Ochieng, 2013)

Such Parameters are:

- Temperature
- Electrical resistivity
- Seismic velocity
- Thermal conductivity
- Streaming potential

Geothermal methods are divided into two groups:

1. Direct Methods
2. Indirect Methods

The direct geophysical methods give detailed information on different parameters that are very much influenced by the geothermal activities, while the indirect geophysical methods give the detailed information about subsurface structures or geological bodies that are very important for the understanding of a geothermal system.

The direct methods include the following:

1. Thermal methods
2. Resistivity Methods
3. Self Potential Methods

The indirect methods include the following:

1. Magnetic Study
2. Gravity Study
3. Active seismic Study

Here, the successful surface exploration results reduce the cost of later stages in the development phase and ultimately save a lot of expenditure at the end of the project implementation.

Sometimes many factors influence choice of methods, which are as follows:

- Geologic Conditions
- Availability of Surface Manifestations

- Geographical setting-terrain etc.
- Cost
- Time Factor
- Specific needs or requirements

2. METHODS OF EXPLORATION

2.1 GEOLOGICAL TECHNIQUES

In geological techniques, a preliminary mapping of the selected prospects is performed, such as major geological units, tectonics and volcanism. Thermal manifestations like hot springs, fumaroles etc. and alteration are also mapped. The physical properties of surface manifestations like temperature, flow rate, conductivity etc are measured.

Without a good understanding of the geology of a prospective area, exploration is a complete guesswork. Three dimensional geological models are the foundations of geothermal exploration and majorly help in the interpretation of geochemical and geophysical signatures of geothermal systems. These 2D and 3D models are made from detailed geologic mapping supplemented with geochemical and geophysical data collection, both of the surface and the subsurface. Detailed surface mapping, structural analysis of faults, interpretation of satellite images, analysis and evaluation of mineral distribution, age–dating of geothermal manifestations, and many other techniques are applied at numerous sites and wells for a reliable model to be achieved (Gupta and Roy, 2007).The application of geological techniques can provide valuable insight into the behavior and evolution of active fracture controlled geothermal system. Permeability distribution, fluid flow patterns and distribution of fractures in the area are also evaluated in geological environments (Wangie, 2012).

The expected geological findings are summarized as follows:

1. Heat sources – magmatic intrusive etc.
2. Permeability – possible fluid flow paths
3. Reservoir – permeable rocks, fault pattern, contacts
4. Possible geo-hazard risks.
5. Conceptualizing sub-surface conditions of an area

2.2 REMOTE SENSING TECHNIQUES

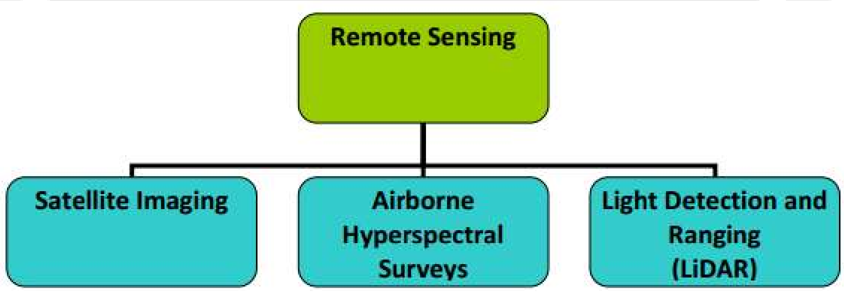

Fig.1 Methods Used in Remote Sensing

Remote Sensing utilizes satellites and/or airborne based sensors to collect information about the given area without being in direct contact with any object. The method can be both passive and active. In passive techniques, various sensors are used to detect natural radiation that is emitted or reflected by the object or area being observed. In active remote sensing, energy is emitted and the resulting signal that is reflected back by the object is measured (Vaughen et al., 2011).

Remote sensing is used in exploration activities of oil and gas and also for geothermal resources. The aim of the study is to carry out preliminary investigation of geothermal prospects through remote sensing approach. This will pave the way for detailed geochemical and geophysical surveys for possible delineation and exploitation of geothermal resource. Remote sensing techniques are emerging as useful preliminary surveying tools for mapping the geology, detecting surface temperature anomalies and identifying geothermal prospects including hydrothermally altered minerals like sinter and tuff in prospective geothermal areas (Calvin et al., 2005). It should be kept in mind that both photographic and thermal infrared sensors can make measurements only to depths of a few microns to millimeters from the surface.

Significant enhancement in wavelength coverage, spectral resolution and image quality over twenty years have resulted in the development of near infrared and thermal infrared imagery tools such as Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), The Moderate-resolution Imaging Spectroradiometer (MODIS). Data sets can be acquired over several wavelength channels (multispectral) as well as over hundreds of wavelengths (hyper spectral). A number of studies have been applied airborne Thermal Infrared Remote Sensing (TIR) to estimate geothermal heat flow in support of the assessment of new geothermal prospects and monitoring of existing developed resources.

This study is aimed at identifying normal background thermal changes so that significant or abnormal changes related to geothermal activity could be recognized. Frequent but low resolution (1 km) MODIS data are analyzed and a method for subtracting the seasonal variation in background thermal flux was developed. High resolution but less frequent ASTER data are successfully used in delineating geothermal anomalous zone. A combination of both day-time as well as night-time spectral imagery data are used for detecting geothermal anomalies. Also vegetation index and land surface temperature data plays an important role to delineate the geothermal prospect for further investigation (Srivastava and Gupta, 2013).

2.3 GEOCHEMICAL STUDY

Geochemical methods are extensively used and play a major role in preliminary prospecting of geothermal resources. Geochemical study also plays an important role in exploration and exploitation. Giggenbach and Goguel (1989) presented a detailed discussion on appropriate analyses, sampling techniques and analytic methods. The major goal of geochemical exploration is to obtain the subsurface composition of the fluids in a geothermal system. The different composition from fluids gives the detailed information about hot spring temperature, origin of the hot spring and flow direction (Mwangi, 2013).

Chemical data of hot water and steam discharges act as useful indicators of the possibility of further exploration in the area including preliminary drilling locations. Integration of structural information from geological, hydrological and geophysical methods, geochemical study can guide for decision making on subsurface exploration by parametric drilling (Arnórsson., 2000). Chemical analysis of fluids extracted from various depths by drilling provides important information on flow patterns of subsurface fluids (Gupta and Roy, 2007). Furthermore, geochemical surveys are relatively inexpensive when compared to geophysical surveys and subsurface investigations by drilling. Therefore, geochemical tools are now widely used in all stages of geothermal exploration and development (Bruton et al., 1997). Geochemical studies of thermal fluids are majorly performed in three steps.

1. Sampling of Water and Gas.
2. Analysis of the fluids.
3. Interpretation of the data

The main objective of the study is to undertake the geochemical analysis of the water samples followed by the synthesis of the geochemical data in order to ascertain the nature of the source(s) of the thermal spring water and interpretation of various subsurface conditions and processes controlling the water chemistry (Gupta and Roy, 2007). Geochemical analysis is useful to evaluate the reservoir temperatures and equilibrium conditions using different geothermometers (Pasvanoglu, 1998)

Fig. 2 Geochemical Analysis

2.4 GEOPHYSICAL TECHNIQUES

The goal of geophysical surveys is to image rock units below the shallow subsurface and determine deeper structure that might represent permeability in a geothermal system. An integration of geophysical techniques like magneto-telluric, gravity, seismic and magnetic methods is used to identify heat sources, permeability structures, fluid flow and drilling targets.

2.4.1 SEISMIC METHODS

A seismic survey is conducted basically in engineering, mining, ground water exploration and site investigation to understand the behavior of the subsurface. Seismic surveys record acoustic echoes from sedimentary rock layers beneath the surface. The various components used in seismic surveys are – energy sources, receiver, cables, recording device, and batteries. An energy source is required to initiate the seismic signal into the sub-surface. It may be a hammer drop or any chemical explosive. Receivers are used to receive the reflected and the refracted signals. Geophones are the commonly used as a receiver in seismic study. Cables are required to connect all the geophones to one common terminal point so that all the received signals come to one common point and can be stacked. A recording device records all the signals in a seismograph or in a computer. Batteries are required to provide energy to the whole system. Processed seismic data can give information about subsurface geology, including rock types and fault structures (our primary intended target). It can also be correlated with gravity surveys to define more accurate velocity models (Jennejohn, 2009)

A seismic survey is a technique that is used to develop images of the rock layers below ground. It is an important step in characterizing a potential site for storage of hydrocarbon and geothermal energy. It also gives the idea about the thickness and depth of different layers and reveals any fault and fractures in those rock layers. Seismic methods is also useful to determine subsurface elastic properties with the help of propagation velocity data of elastic waves and can be very helpful in obtaining structural information of the subsurface or even to outline a potential reservoir boundary.

Fig. 3 Seismic Acquisition

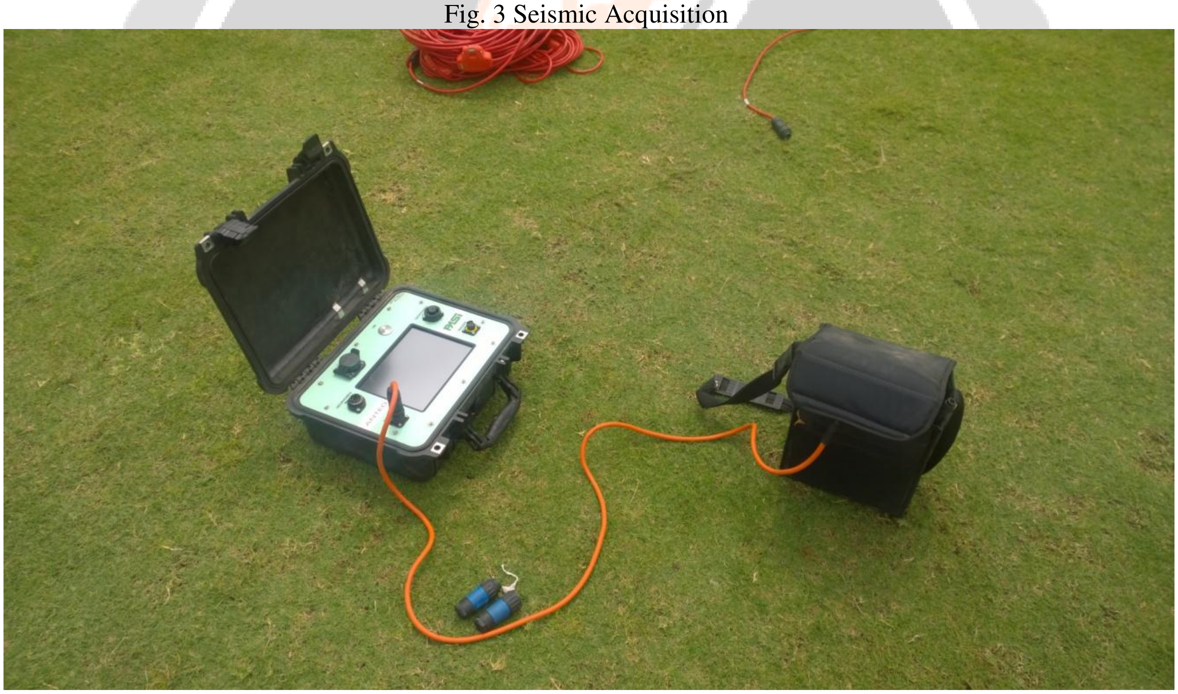

Fig. 4 Receiver and Battery of Seismic Instrument

There are mainly two types of techniques are used in seismic:

1. Refraction Seismic
2. Reflection Seismic

REFRACTION SEISMIC**:** The seismic refraction method is one of the most commonly used geophysical methods in engineering, mining, ground water, exploration, geothermal exploration and environmental site investigation. The refraction method is utilized to provide detailed information on the distribution and thickness of sub surface layer with characteristic seismic velocities. Seismic refraction surveys have been used to a limited extent in the area of geothermal system because of the complexity of geological structure beneath the subsurface

Seismic refraction surveys are used to determine the compressional wave velocities of different materials from the ground surface to a specified depth within the earth. In many cases the objective of a seismic refraction survey is to determine the configuration of the bedrock surface and the compressional wave velocities of the underlying materials. The information which is obtained from a seismic refraction survey is used to compute the depths to various subsurface layers and characterize the configurations of these layers. It also gives the detailed information about the thickness of the subsurface layers and the velocity contrasts between the layers which governs the effectiveness and the accuracy of the survey. The source of the geothermal body may also be detected with the help of reflection seismic (Gupta and Roy, 2007).

REFLECTION SEISMIC*:* Reflection seismic methods are more commonly used in geothermal exploration, as they give high lateral resolution compared to refraction seismic and require much shorter profiles and therefore less shot energy.Seismic reflection surveys have been used successfully in petroleum and geothermal exploration projects and useful to identify the better prospect. The information obtained from seismic reflection surveys can be used to define the geometry of the different subsurface layers and structural features along with faults and fractures (Young et al., 2012).

2.4.2. GRAVITY METHODS

The gravity method is passive geophysical exploration method that involves the measuring of the acceleration due to the Earth's gravitational field. The variations in gravity are due to density lateral changes of the subsurface rocks. The equipment used to measure the variations in the Earth's gravitational field is called a gravimeter. The gravity values are expressed in mill gals (mGal), a unit of acceleration where 1 Gal equals 1 cm/sec^2 (Sahajpal et al., 2015)

The measured Bouguer gravity data (over a specified grid) gives the effect of gravity due to sediments and basements. The objective of the survey is to identify anomalies having density different other than that of the background. Once necessary corrections are applied to the data, the Bouguer gravity is separated to regional and residual. And the residual gravity interpretation gives the Geophysical anomalies (Sircar et al., 2015).

Fig. 5 Gravity Data Acquisition

Gravimeter measures absolute and relative gravity at a particular station point. There are two kinds of gravimeters. An absolute gravimeter measures the actual value of gravity by measuring the speed of falling mass using a laser beam. This meter achieves a precision of 0.001 mGal; a second type of Gravimeter measures relative changes in gravity (mGal) between two locations. This instrument uses a mass on the end of the spring that stretches where G is stronger. This kind of meter can measure gravity with precision of 0.01mGal in about 5 to 7 minutes (Rivas, 2009).

This method is well applied when identifying dense or less dense subsurface anomalies which are vital to locate in the geothermal exploration projects. Subsurface faults lines are also identifiable with gravitational methods. These faults are often identified as prime drilling locations as their densities are much less than surrounding material. Changes in groundwater levels may also be measured and identified with gravitational methods (Gupta and Roy, 2007).

2.4.3 RESISTIVITY AND MAGNETOTELLURICS

The magnetotelluric method is passive surface measurement of the Earth's natural electric field and magnetic field in orthogonal direction (Sahajpal et al., 2015). The magnetotellurics technique or magnetotellurics is an electromagnetic geophysical exploration technique that gives the better of images the electrical properties of the earth. The method is used to determine the resistivity of the earth ranging from a few tens of meters to several hundreds of kilometers. MT generally refers to recording of 10 kHz to 0.001 kHz or as low as 0.0001Hz (Vozoff, 1991).

The MT signals are generated from two sources.

1. The first source is at lower frequencies generally less than 1 Hz. The origin of that signal is from the interaction of the solar wind with the earth's magnetic field. Here solar wind emits highly charged ions which travels into space and disturbs earth's magnetic field and produce low frequency electromagnetic energy that penetrates into the earth (Caginard, 1953).
2. The second source is at higher frequencies generally greater than 1 Hz. It is created by thunderstorm activity. The energy created by these thunderstorms travels around the earth in a wave form between the earth's surface and the ionosphere, with part of energy penetrates into the earth (Keller and Frischknecht, 1966).

The MT method is very powerful geophysical tool to detect enhanced conductivity structure in the crust due to aqueous fluids, metallic minerals, interconnected graphite films and partial melt. Supplementary data like gravity, heat flow and seismic velocities are necessary in most cases to distinguish the source of the conductivity (Heise et al., 2006).

Fig. 6 MT Equipments

Fig. 7 MT Acquisition

Electrical Resistivity methods have been very successfully used in geothermal exploration to identify subsurface anomalies. Change in the electrical resistivity of the rock fluid volume is dependent on hydrothermal alteration and heat flow data (Moskowitz and Norton, 1977). Resistivity sounding and profiling are two most commonly applied procedures on the field for estimating underground resistivity. The objective of resistivity sounding is to estimate variation of resistivity values with depth below a given point. Such type of measurements are required when the ground consists of a number of more or less horizontal layers. The object of resistivity profiling is to detect the lateral variation of resistivity of the ground. This kind of survey is undertaken to delineate underground anomalies which has low resistivity values (Moskowitz and Norton, 1977).

2.4.4. Magnetics

The main objective of the magnetic study in area of geothermal is to contribute with information about the relationship among the geothermal activity, the tectonic and Stratigraphy of the area by means of the anomalies interpretation of the underground rocks and magnetic properties of the rock. The data interpretation from the magnetic study reflects the differences in local abundance of magnetization and the information from above is useful to locate faults and geologic contacts (Rivas, 2009). Magnetic study results also identify the Curie point or Curie temperature. At the Curie point, materials will change from ferromagnetic to paramagnetic. This Curie temperature will help to estimate future plant productivity (Nwankwo, 2009).

3. CONCLUSION

Geothermal exploration is a multidisciplinary task which entails activities like geological survey, geochemical survey and geophysical survey. No single method is universally superior but Electrical methods and Geochemical Surveys are usually useful to delineate the geothermal prospect. The epitome of exploration is to determine the existence of a geothermal resource and subsequently identify suitable drilling sites based on integrated data obtained by all exploration methods. Geothermal exploration is normally carried out on a step by-step basis with each of the phases involved aimed at gradually eliminating the less interesting areas and focusing on the most promising ones. Integrated multi – method and dynamic approach is important for future investigation in area of geothermal exploitation. Successful surface exploration will avoid unnecessary expenditure when the project of such kind enters in the development phase.

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