



Full Length Research Paper

Geothermal Gradient Calculation Method: A Case Study of Hoffell Low- Temperature Field, Se-Iceland

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ABSTRACT

The study area is a part of the Geitafell central volcano in southeast Iceland. This area has been studied extensively for the exploration of geothermal resources, in particular low-temperature, as well as for research purposes. During the geothermal exploration, geological maps should emphasize on young corresponding rocks that could be act as heat sources at depth. The distribution and nature of fractures, faults as well as the distribution and nature of hydrothermal alteration also have to known. This report 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 familiarize the author with geothermal gradient mapping, low-temperature geothermal manifestations, as well as studying the site selection for production/exploration well drilling. Another goal of this study was to make geothermal maps of a volcanic field and to analyse if some relationship could be established between the tectonic settings and the geothermal alteration of the study area. The geothermal model of the drilled area is consistent with the existence of a structurally controlled low-temperature geothermal reservoir at various depths ranging from 50 to 600 m. Televiwer data show that wells ASK-29, ASK-82, ASK-56, ASK-50 and ASK-83 in the study area have open fractures and show a comparatively high geothermal gradient indicating that further drilling for exploration/production should be executed. A geothermal map is presented from which possible drilling targets for production and exploration are suggested.

Keywords: Volcano, Geothermal resources, Exploration, Drilling

INTRODUCTION

Location, topography and climate of the study area

The study area, located in southeast Iceland (Fig.1), is home to a low-temperature geothermal field, which is about 400 km southeast of Reykjavik, the capital city of Iceland. It is located at 64°42'20"N – 64°44'20"N and 15°04'20"E – 15°06'30"E. Within the region the extinct central volcano of Geitafell is found, but it was active five million years ago. Today the deep the roots of the volcano can be seen, due to glacial erosion. The topography comprises mountains of volcanic rocks and a valley mostly covered by alluvium and vegetation. The altitude is between 30 and 500 m over sea level. Since the study area is close to the Atlantic Ocean, it is affected by the Irminger current, which greatly moderates the climate along Iceland's southern and western coasts. The climate of the area is characterized by a cold winter and a

moderate summer. The area receives a relatively high mean annual precipitation, between 1100 and 2100 mm per year. Winter is cold with a mean daily temperature in the range between -2 and -4°C. Summers are fairly warm, with a mean monthly temperature of about 8-10°C (Einarsson, 1991). The weather is highly unpredictable since rainfall may occur at any time, and snowfall can prevail in the winter. There are two glacial rivers Austurfljot and Sundurfljot draining the area. These are braided river systems which flow across a sandur plain, known as Hoffellssandur, in which the mountain of Svinafell (323m) is located.

Background and objectives

Bangladesh is one of the poor and developing countries which has suffered from serious shortage of electricity.



FIGURE 1: Location map of the study area

Not more than 50% of the country has electricity coverage. Frequent power cuts also cause serious problems. In order to improve the electrical supply, the Geological Survey of Bangladesh (GSB) initiated a drilling programme in 2010 exploring possible geothermal resources in the north-western part of the country. During the exploration phase of geothermal prospects, geological mapping of surface geothermal manifestations and low-temperature surveys are essential to evaluate geothermal resources. Therefore, on the request of GSB, The Geothermal Training Programme of the United Nations University (UNU-GTP) in Iceland kindly approved the present author to attend the Programme in the specialized field of geological exploration in 2013. This study is a part of a six month training course at the UNU-GTP in Iceland in 2013 commencing in April. The objective of the study was to provide the author with training in geothermal mapping using the volcanic field at Hoffell in SE Iceland as a study area. This is a low-temperature geothermal field and the author was trained in exploring such an area and how to analyse, interpret and present the data which was gathered.

Previous work

The geothermal area is mentioned in several reports but the first comprehensive study of the geology of the area appeared in the doctoral of Gudmund Ómar Fridleifsson (1983). The field was explored for geothermal application in 1992 when the first wells were drilled. Arni Hjartarson et al. (2012) used a televiwer in order to get a better idea of the direction and angle of fissures and faults in 7 wells. In September 2012, air temperature, dimensional, neutron and gamma measurements were completed in

some wells in the area. Besides them some studies also completed about the studied surrounding area. Burchardt and Gudmundsson (2009) worked on the infrastructure of Geitafell volcano, southeast Iceland.

Low-Temperature Activity

The low-temperature areas are fracture and fault dominated and derive their heat from convection within the cooling lithospheric plate. The low-temperature activity in Iceland associated with recent sub-vertical fracturing and faulting of older crust of the American plate and Hreppar microplate which heat sources is hot rocks at depth. According to Arnórsson and Gíslason (1991) low-temperature geothermal activity in Iceland is the consequence of one or more of the four following scenarios:

- Deep circulation of groundwater from higher to lower elevation along fractures or other permeable structures driven by a hydraulic head.
- Convection in young fractures formed by deformation of older crust.
- Drift of high-temperature geothermal systems out of the active volcanic belts accompanied by cooling due to displacement from their magmatic heat source.
- Intrusion of magma into fractures or other permeable formations by the margins or outside the volcanic belts.

The heat-source for low-temperature activity in Iceland is believed to be the island's abnormally hot crust, but faults and fractures, which are kept open by ongoing tectonic activity, also play an essential role by providing channels for the water that circulates through the systems, and mines the heat. Outside the volcanic zones the

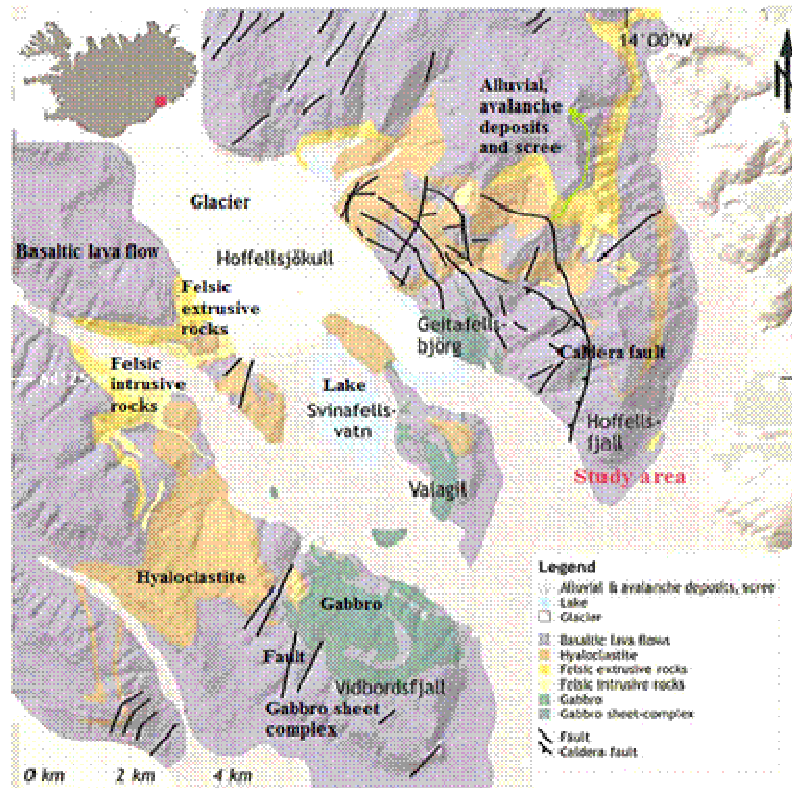


FIGURE 2: Geological map of the study area (modified from Fridleifsson, 1983).

temperature gradient varies from about $150^{\circ}\text{C}/\text{km}$ near the margin to about $50^{\circ}\text{C}/\text{km}$ farther away (Arnórsson et al., 2008). More than 250 separate low-temperature areas with temperatures not exceeding 150°C in the uppermost 1,000 m are found, mostly in the areas flanking the active volcanic zones (Burchardt and Gudmundsson., 2009).

Utilization of low-temperature geothermal energy

Low-temperature geothermal energy has been utilized for many purposes, both direct uses and binary power plants. Initially in Iceland it was used for bathing and washing. The first trials to use geothermal energy for space heating were made in the middle of the 18th century in Iceland. Direct heating in all its forms is far more efficient than electricity generation and places less demanding temperature requirements on the heat resource. Heat may come from co-generation with a geothermal electrical plant or from smaller wells or heat exchangers buried in shallow ground. As a result, geothermal heating is economical over a much greater geographical range than geothermal electricity. Where natural hot springs are available, the heated water can be piped directly into radiators. Low-temperature geothermal heat is also used by many companies to dry some products, like fish heads and wood. The heat is also used for some other things for example to bake bread and heat

up footpaths, streets and parking places. Geothermal heat supports many applications. In Iceland, Reykjavik and Akureyri pipe hot water from geothermal plants below pavement to melt snow. District heating applications use networks of piped hot water to heat buildings in whole communities. Bathing and swimming is the most common use of low temperature geothermal energy. The study area of Hoffell in southeast Iceland is a home of low temperature geothermal energy. The study area of Hoffell in southeast Iceland is a home of low temperature geothermal energy. The main use of this energy in house heating purpose of adjoining area. More than 50 wells have been drilled for supplying the hot water which directly control by Iceland geosurvey (ISOR). Some little use in bathing too.

Geothermal Area of Geitafell Central Volcano, Southeast Iceland

The study area is partly related to the extinct Geitafell Central Volcano. The total thickness of strata in the volcano is 2700 m which indicates that the volcano was a high mountain. The volcano has two major structural elements; 1) a caldera fault and 2) a flexure zone. It was active about 5 million years ago but glacial erosion has since exposed its core ((Fridleifsson, 1983)). The study area of Hoffell is near to the caldera fault but outside of this caldera which clearly mentioned in geological map of

the study area. This volcano is located northwest of Höfn town with the deepest glacial erosion and the glacial valleys are related to the Höffellojokull and other outlet glaciers of the ice sheet which cut the centre of this. So, the study area of Hoffell is the part of Geitafell central volcano.

Geology and tectonic settings of study area

The Geitafell central volcano, which is the best exposed and deeply eroded central volcano in southeast Iceland, was formed within a rift zone (Saemundsson, 1979). The study area is located within this volcanic complex. It was active five to six million years and activity lasted for about a million years. The area consist mostly of tholeiitic rocks of which 60% are basaltic lavas and 30% hyaloclastites (Fig. 2 above). Several gabbro bodies are exposed in its core representing the uppermost part of an extinct crustal magma chamber surrounded by a dense swarm of inclined sheets. Intrusive rocks of the Geitafell volcano are composed of several gabbro, granophyre and felsite intrusions, together with dyke and sheet swarms. A dense swarm of inclined (cone) sheets is in direct contact with the chamber (Fridleifsson, 1983). The sheets and basaltic dykes range from aphyric porphyritic dolerites to aphyric and fine-grained, porphyritic basalt. The overall pattern of the tectonics relates to divergent movement of crustal plates and is accompanied by inflow of magma to all crustal levels. The general characteristics of the dilation tectonics involved are open fissures and grabens at the surface but normal faulting at depth (Fridleifsson, 1983). During the life-span of a typical Icelandic volcanic complex there are series of relatively short magmatic-tectonic active episodes between longer dormant periods (Björnsson et. al., 1977). It is evident that considerable interactions between tectonic and magmatic forces occur during active episodes, with the actions of both reciprocal effects upon the other on a whole range of scale. While tectonic activity, in general, allows release the fluid pressure of the system. High fluid pressure may built up in a neighbouring magma and hydraulic fracturing may result. Any sort of fracturing processes will result in fluid flowage and directly affect the overall permeability of the system (Fridleifsson, 1983).

Mineralogical Evolution

The mineragical distribution within the hydrothermal system is represented by the five mineralogical zones (Fig.3 below). The five mineral zones all relate to the formally active high-temperature geothermal system (Fridleifsson, 1983). They are;

- Epidote zone (Ep)
- Chlorite zone (Ch)
- Androdite zone (Gr)
- Actinolite zone (Act)
- Sulphide zone

In particular, four of these zones (chlorite→episode→garnet→actinolite) show the progressive appearance of the index minerals within both the host rocks and the intrusive rocks (including phase-11). Four to six major mineral vein systems were formed in the volcano. Upon progressive rise in geothermal gradient within the volcano the vein mineral deposition changed to silica precipitates (jasper→chalcedony→quartz) and smectite→chlorite. A high-temperature system then became active upon the emplacement of the central gabbros (IP-2) at shallow depths and a sharp change in vein deposits took place. The veins formed after the IP-2 emplacement show distinctive depth and spatially related variation, generally involving higher temperature mineral assemblages at depths and towards the volcanic centre. The types of minerals formed in veins related to the high-temperature system within the actinolite zone include epidote, quartz, calcite, actinolite, androdite, and albite. In the overlying mineral zones actinolite, quartz, albite and wairakite sequentially disappear from the vein system, while within the upper part of the epidote zone epidote and prehnite are more or less restricted to mineral veins and wall rock zones within and in the vicinity of some members of a particular intrusive phase-10 (IP-10) and or in the vicinity of the caldera fault. The last vein systems invariably contains zeolites, chiefly, stilbite and heulandite, related to cooling of the high-temperature system (Fridleifsson, 1983).

Intrusive Phase and Mineralogical Evolution of The Study Area

The study area is mainly composed tholeiitic lavas and dykes but sheets and faults are also found. The strike direction is north-west and dip direction is north-east (65°-80°NE). According to the description of several intrusive phases, it may be suggested that the study area of Hoffell is under the intrusive phase-5. Dolerite sheets are most common in intrusive phase-5 which are also found randomly near the Hoffell farm area (Fridleifsson, 1983). Three main mineral zones are found in the study area. Epidote, androdite and actinolite are most common but chlorite zone is also found but scarcely. The studied area is mainly composed of a gabbro sheet complex with some felsic extrusives. Some dykes and cone sheets which sometimes cuttings each other also mentionable in this area. So this area also part of intrusive phases 6, 10 and 12 (Fridleifsson, 1983).

Intrusions

In this study area, several types of intrusions are found. There are gabbro intrusions which are associated with a large number of intrusive sheets.

Gabbro intrusions: This intrusion is to have diapiric form with a steeply plunging feeder and pronounced tabular

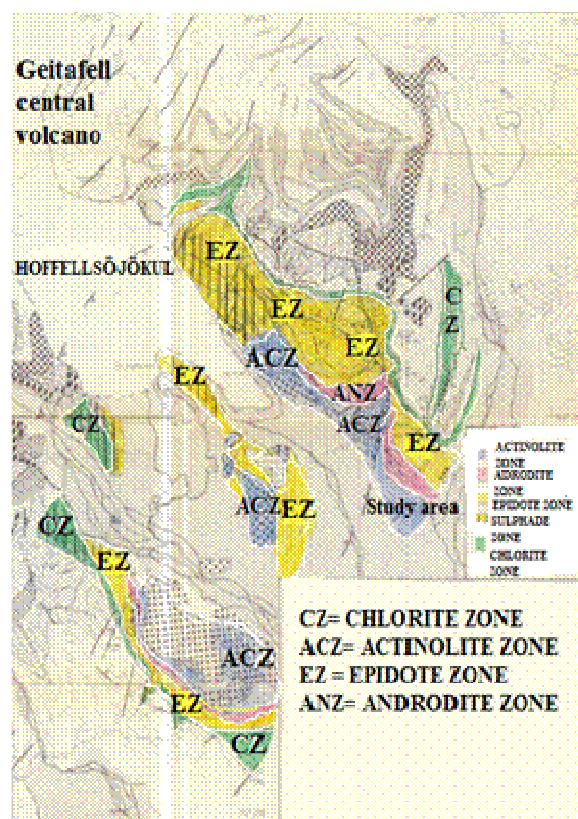


FIGURE 3: Map showing the mineralogical alteration as well as several zones of the study adjoining area, SE-Iceland (modified from Fridleifsson, 1983).

jointing. This gabbro is the most extensively studied which rises from the sandur plain. Seven main mineral vein systems were emplaced within the Geitafell gabbro (Fridleifsson, 1983).

Dykes: The ratio of dykes in the area is high in some areas they make up to 40% of the strata. The main trend is NW-SE direction and sometimes crosscutting the cone sheets. The apparent strikes observed of dykes were 55° - 70° NW and the dip steeply to the southwest (65 - 80° SW).

We have mainly two types of dykes, regional dykes usually thick (1.5-2m) and steeply dipping cone sheets average .6 m thick (Fridleifsson, 1983). Cone sheets and dykes are fine basalt to coarse dolerite (Annels, 1967).

Cone sheets: The cone-sheet swarm is of doleritic composition, the dykes usually being 0.5-0.7 m thick but sometimes up to 1.5 m (Annels, 1967). They are greyish green in colour and are readily distinguished from other cone sheets of other intrusive phases. The sheet swarm is widely distributed in the area dipping towards the SW or NE. Some sheets are almost vertical as they intrude through the lava pile.

Fractures and Veins

Fracture systems act as conduits for fluids and play an important role in the extraction of geothermal energy in

both liquid- and vapour-dominated fields. Several types of fractures developed in a rock formation in both for natural. Fault, joint, fault zone, compaction, deformation are the fractures which are developed by the natural activity. Induced fracture which produced by human activity. These fractures are directly related to the geothermal system of an area. Fractures are also affected by several types of mineral veins which are settled within the fractures of a rock formation. (Fridleifsson, 1983). Low-temperature alteration zone which is characterized by the presence of zeolites and low-temperature clays (Smectite). The zeolites present as secondary minerals in this area. In the study area of Hoffell some wells (ASK-29, ASK-50, ASK-57, ASK-82 and ASK-86) shown open fracture which known by TV data.

Geothermal Mapping

Geothermal or temperature gradient is a physical property that describes in which direction and at what rate the temperature changes in units of degrees (on a particular temperature scale) per unit length. The rate of change in temperature in a given direction, especially in altitude a temperature gradient is the change of temperature with depth Geothermal energy is heat from underground or is the energy stored in the form of heat



FIGURE4: Photograph showing the dykes (used on Hammer), Hoffell area, southeast Iceland.

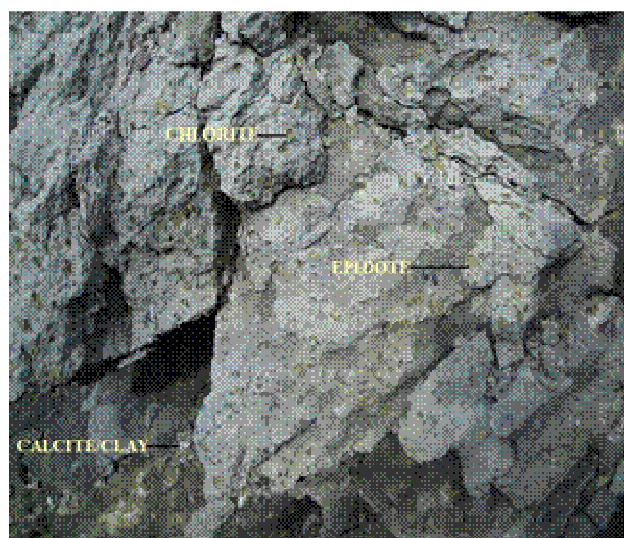


FIGURE5: Photograph showing the several vein fillings of studied area, green colour fillings indicated chlorite, yellowish green epidote and white colour is indicated calcite or clay mineral, Hoffell area, southeast Iceland.

beneath the earth's surface. In this energy, the temperature gradient is the most important and common element. Heat flow is directly related to the temperature gradient. In the study area the temperature gradient are collected by several steps during the study period, for the first time, measured the well temperature with respect to

different depth interval, in this way several temperature measured at several depth in a well. Then the collected highest temperature in that of depth as well as lowest temperature in starting depth was sorted. The temperature gradient is measured by difference between the lowest and highest temperature which divided by the

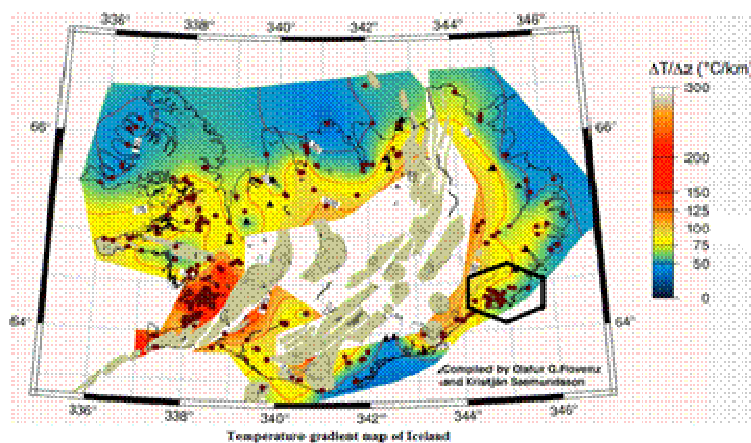


FIGURE 6: Geothermal gradient map of Iceland which showing the regional gradient 40°C/km-60°C/km of the study area (Flóvenz and Sæmundsson, 1993)

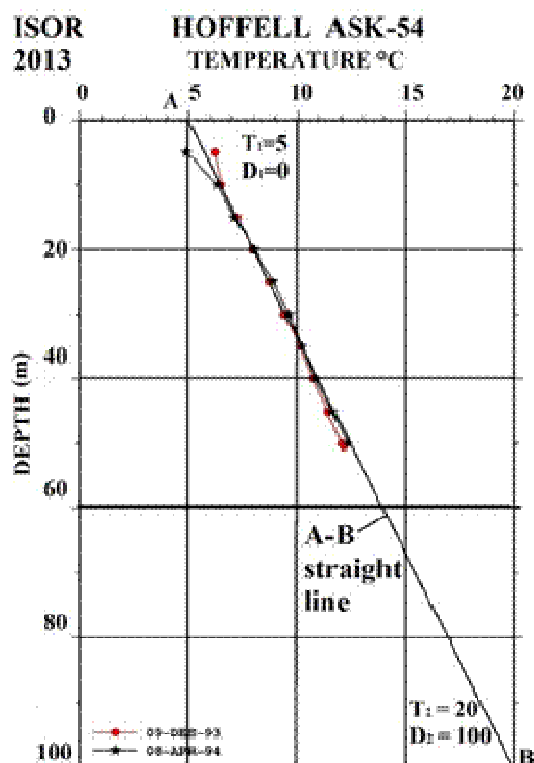


FIGURE 7: Temperature versus depth relation.

difference of lowest and highest depth. In the figure 14 shown that temperature versus depth which was collected at different interval. The blue colour straight line in Fig.14 cut the maximum point of temperature at different depth. So, we can easily collect higher temperature at higher depth and lower or starting temperature at that of depth. The gradient calculation have been conducted by the equation as well as with the help of this figure 13 are clearly describing below.

Gradient calculation

The gradient calculations have been conducted by the equation as well as with the help of this figure 14 are

clearly described. Fig7 showed the relationship between temperature and depth. A-B straight line drew which cut the maximum points of temperature versus depth points. Then calculated the dt and dz from the figure.

$$\text{Temperature Gradient (G)} = \frac{dT}{dz} = \frac{T_2 - T_1}{D_2 - D_1}$$

Where, T_1 = Starting temperature of straight line;
 T_2 = Ending temperature of straight line;
 D_1 = Starting depth of straight line;
 D_2 = Ending depth of straight line;

Where, $T_1 = 5$
 $T_2 = 20$
 $D_1 = 0$

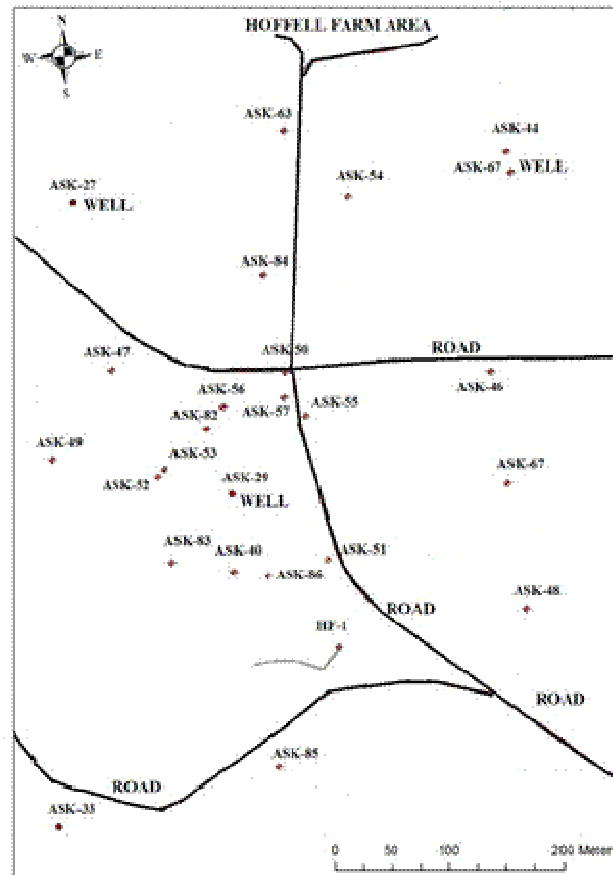


FIGURE 8: Map showing the location of different wells and roads of study area, Hoffell, Southeast Iceland.

$$D2 = 100$$

$$(G) = \frac{T2-T1}{D2-D1} = 20-5/100-0$$

$$\text{So, } G = 0.15 \times 1000 \\ = 150 \text{ } ^\circ\text{C/km}$$

The temperature gradient of Hoffell ASK-54 is 150°C/km which calculated by the above formula. In this way calculated the temperature gradient of several wells in the Hoffell area. After calculation the gradient is plotted to the certain well location in a map (Fig. 8) and drawn isotherm lines and resulted is a gradient map (Fig. 9) of the Hoffell low-temperature system.

Geothermal gradient map of the study area

The geothermal gradient calculation is one of the most important and useful method which applied in both of low and high temperature geothermal field. In Iceland many exploitable geothermal systems have been discovered by this method even where there were no surface manifestations. With the help of geothermal gradient prepare a geothermal map of any geothermal based study area. The study area of southeast Iceland is one of the low-temperature geothermal field of Iceland where

there is no surface manifestation. Any geothermal system which is confined to a fracture of local extent so that this method has proved most useful in this area. The calculated temperature gradient of different wells of the study area were plotted to their well location (Fig. 9). Then contour lines drawn with respect to certain temperature interval. In this way prepared the geothermal map (Fig.10) of Hoffell study area in southeast Iceland. This map also figure out the road of the study area. In the research making, a geothermal map (Fig.10) from heat measurements in several gradient wells at Hoffell area, which shown the different temperatures zones (three zones) of the area (Fig.10). The red colour bounded zone is the highest temperature (>200°C/km) zone of the study area. The depth of these wells are varies from 50 m to 600 m and temperature gradient varies from 100 °C /km to 210°C/km. Maximum temperature gradient shown as 210° C/km in ASK-29. 23 more well's temperature gradient of the study area have been measured, some of wells (ASK-29, ASK-50, ASK-57, ASK-82 and ASK-86) shown veins as well as open fractures which might be fractures controlled with an up flow of water. Televiewer data also showed their trending of NNE-SSW and W-E WSW-ENE direction. Figure 10

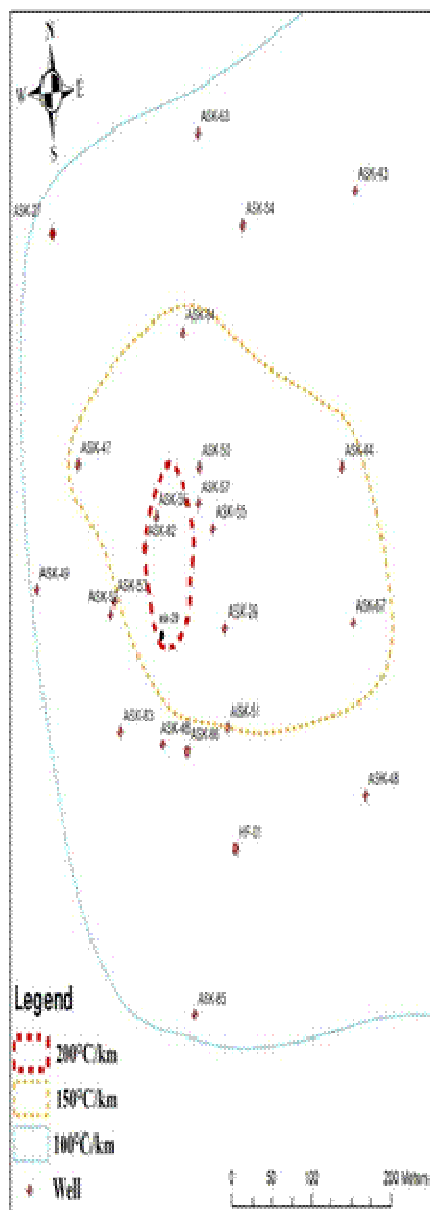


FIGURE 9: Geothermal map which showing the temperature gradient of the study area, Hoffell, Southeast

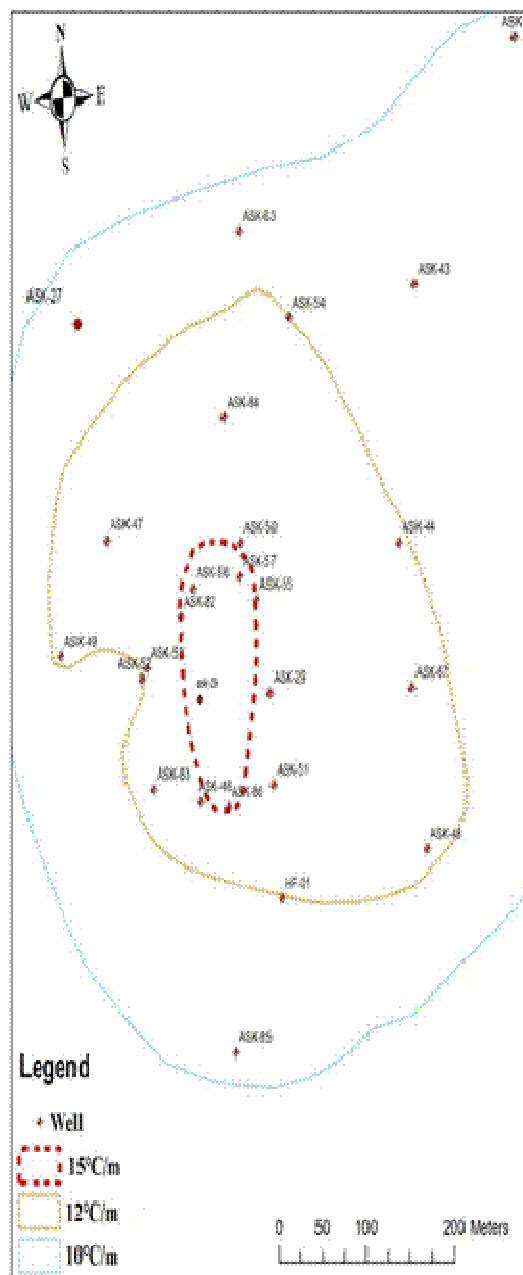


FIGURE 10: Temperature map which showing the temperature condition (50m depth) of the study area, Hoffell, Southeast Ireland

showing the temperature condition at 50 m depth of different wells of the study area. This map also shown three types of zones according to their temperature changes and red colour bounded zone shown the highest temperature ($>15^{\circ}\text{C/m}$). In fig.11 showing the comparison between temperature map and gradient map of the study area. This map shown the highest gradient zone (black colour bounded) is within the highest temperature zone (red colour bounded). This is clearly showing the N-S trend of maximum heat with flow to the E and SE direction.

Interpretation of the Fractures and Veins of Different Wells

23 more well's temperature gradient of the study area have been measured. The depth of these wells are varies from 100 m to 600 m and temperature gradient varies from 100°C to 220°C . Some of wells showed veins as well as open fractures which are indicating of good reservoir. Open fractures-fault zones are NNE-SSW and W-E WSW-ENE direction. There are three structural trends which are NE-SW to NNE-SSW, W-E and NW-SE direction. The wells of maximum temperature dominant

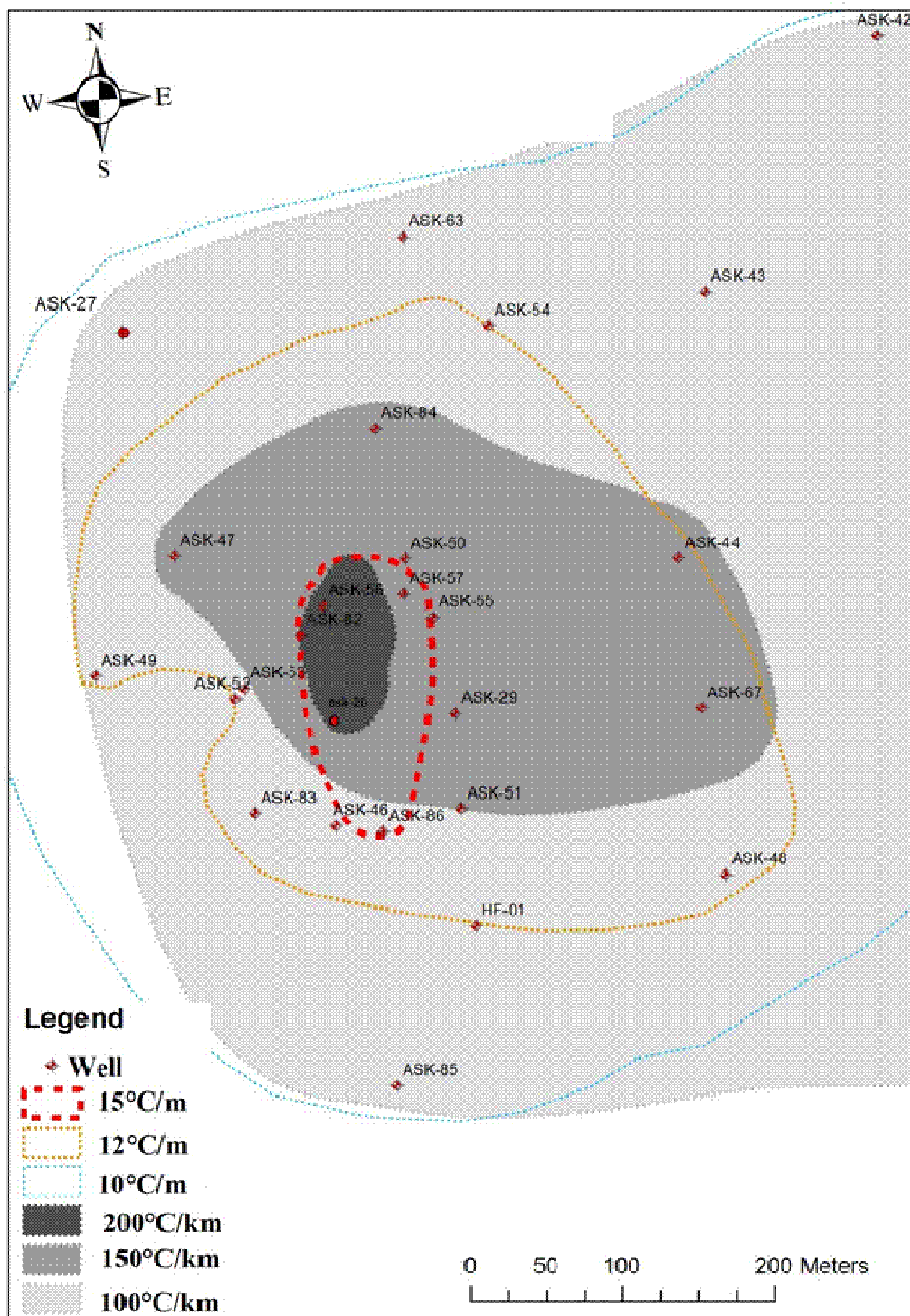


FIGURE 11: Comparison between temperature map and gradient map of the study area, Hottell, Southeast Iceland.

Table 1. Short summary of veins (ASK-29, ASK-50, ASK-57, ASK-82, ASK-85 and ASK-86) that appeared in the Televiewer measurement at Hoffell study area.

Well no	Veins that appeared from the TV measurement (m)		TV measurements were performed at some veins that are not at a depth
ASK-29			126, 129
ASK-50	74	Viewed as open fractures	
ASK-57	465	Viewed as large open fractures at depth of 458 m	113, 121, 296
ASK-82	180	Viewed as open fractures	
ASK-85			
ASK-86	485	Viewed as large open fractures at depth of 486.35 m	228, 300

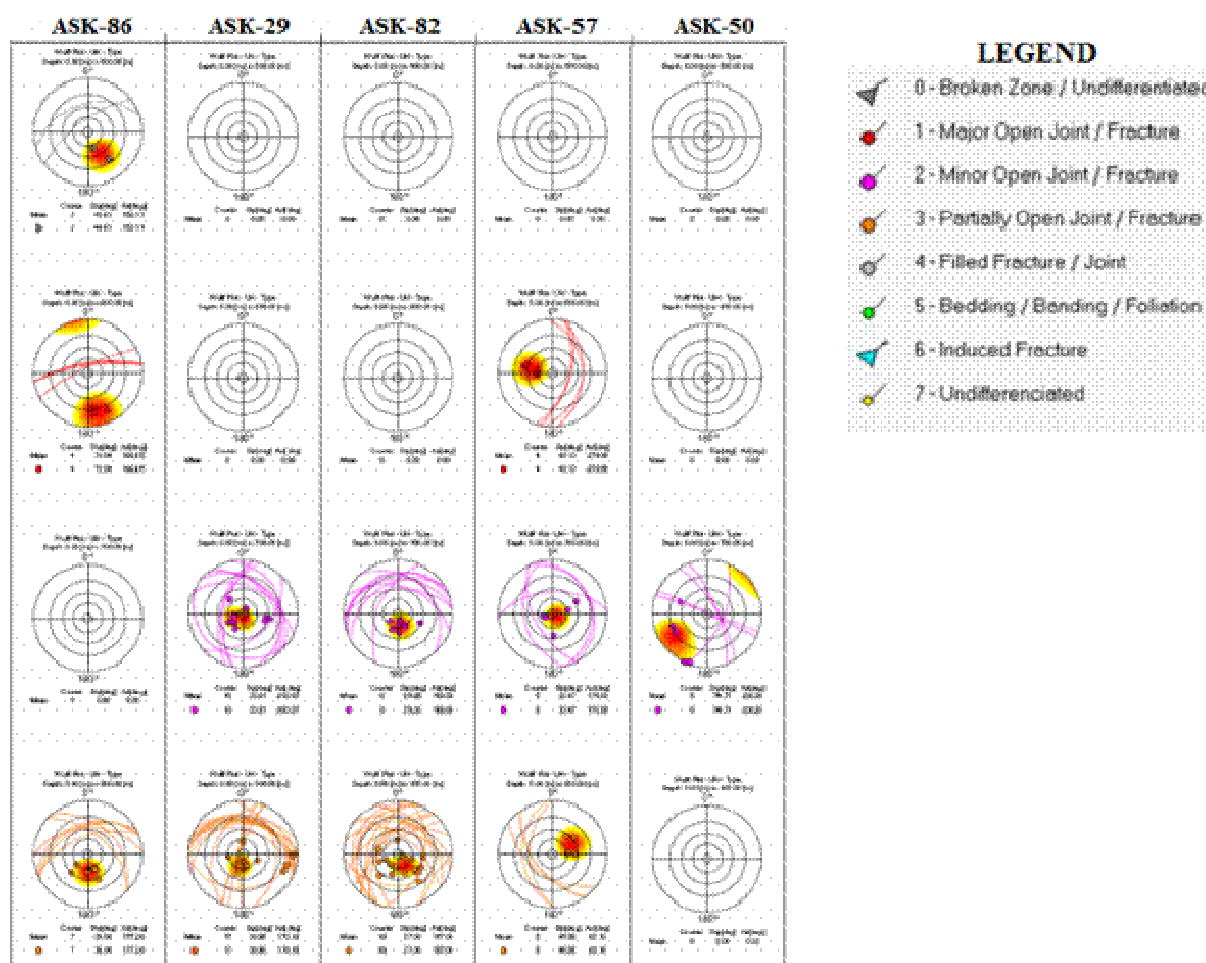


FIGURE 12: Map showing the 3 main structural trends and open fractures-fault zones direction of different wells at Hoffell area, southeast Iceland.

area have been demarcated (ASK-29, ASK-50, ASK-57, ASK-82 and ASK-86) and some of these wells condition as well as fractures and veins are describing below (Only ASK-29 and ASK 85 are no good data which are measured from TV).

ASK-57

The temperature gradient of this well is 169 °C/km and ASK-50 is about 50 m north from this well shown 160 °C/km, ASK-55 is 55 m south-east from ASK-57 shown 173 °C/km. So ASK-57 is in comparatively higher

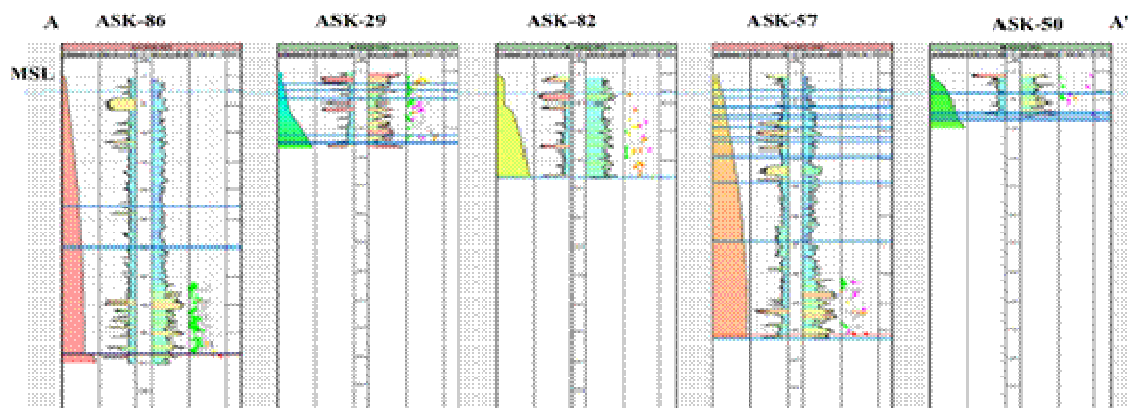


FIGURE 13: Wells cross section (T, GR, NN and TV-Picks; blue line: feed zone)

temperature region. From the Televiwer data, the vein is 458.14 m depth, which shows a large open fracture. Here the measuring device set at 465 m. 4 major open fractures are counted which average dip direction (43°) almost west. 5 minor fractures are observed and their dip angle are S 33° E. 5 partially open fractures are also found which dip direction N 45° E (Fig.12). This is a deep well which feed zone is in greater depth (Fig.13)

ASK-50

The temperature gradient of this well is 150 $^\circ\text{C}/\text{km}$ hole which is also high temperature region. From the Televiwer data the vein is 74 m depth, which shows an open fracture. 5 major open fractures are counted which average dip direction S 74° W and no minor/partially open in this well (Fig.12). Feed zone are found in shallow depth, it is 150 m depth well which is the shallowest open fracture bearing well.

ASK-82

The temperature gradient of this well is 220 $^\circ\text{C}/\text{km}$ which is the highest temperature gradient. From the Televiwer data, the vein is 180 m depth, which shows a large open fracture. This well is artesian type which in the south-eastern part of the study area. 2 major open fractures are found which dip direction almost 30° south, so it is difficult to identify that is contact or joint or fault. 18 partially open fractures are also observed and their dip direction S 37° E (Fig.12). Feed zone is observed in shallow depth (Fig.13)

ASK-86

The temperature gradient of this well is 180 $^\circ\text{C}/\text{km}$. From the Televiwer data, the vein is 485 m depth, which shows a large open fracture. Here the measuring device set at 486.35 m. 4 major open fractures (S 73° E) and 7 partially open fractures are also found which dip direction almost (39°) south (Fig.12). Feed zone is found in greater depth (Fig.13) and this is a deep well.

ASK-29

The temperature gradient of this hole is 210 $^\circ\text{C}/\text{km}$ hole which shown 10 large open fractures and their dip direction S 33° W. 17 partially open fractures are also found which dip direction almost (40°) south. Highest temperature gradient (210 $^\circ\text{C}/\text{km}$) was calculated. This well and adjoining area may be the high temperature prospect zone. This well is 150 m depth which feed zone is in shallow depth and clearly shown in well cross section (Fig.13). This well is the shallowest well among the all measuring well.

CONCLUSION AND RECOMMENDATIONS

The study area is south-eastern part of Geitafell central volcano in southeast Iceland which is the most important area on account of low-temperature geothermal field. The area is mainly studied with respect to temperature gradient as well as geological information. The volcanic complex is deeply eroded and formed in the rift zone. Which mainly composed of tholeiitic rocks of which 60% are basaltic lavas and 30% hyaloclastites. The general characteristics of the dilation tectonics involved are open fissures and graben at the surface and normal faulting at depth. During the study period 23 wells experimented and measured their temperature gradient to knowing the subsurface temperature of the study area. The area is mainly studied with respect to temperature gradient as well as geological information. In this study area heat flow gradually to the eastern side from the western side which indication of east dipping fracture. Measured temperature gradient of different wells as well as the televiwer data, is clear that ASK-29, ASK-56, ASK-82, ASK-57 wells and their adjoining area is the highest temperature zone, this data also showing several veins at certain depth or open fractures which are NNE-SSW and W-E WSW-ENE direction. The highest temperature zone is showing the more than 200 $^\circ\text{C}/\text{km}$ gradient. Though there is no surface manifestation, it is clear that the subsurface

temperature abnormal in this region. I would like to propose the next well on the eastern part of the highest temperature zone. The surveyed area of southeast Iceland is a vast region which geologically controlled by the Geitafell central volcano. It is one of the most important region with respect to geothermal energy and geologically. So, it should be needed to detail geological, geophysical survey to know the real pictures of geothermal and geological condition as well as tectonic framework of the area which can be also helpful to identify the best locations from which to exploit the heat source.

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REFERENCES

- Annels AE (1967). The geology of the Hornafjörður region, southeast Iceland. University of London, PhD thesis, Pp120.
- Arnórsson S, Grislasson G (1991). Geothermal systems in Iceland: structure and conceptual models- II. Low-temperature areas. 24(5/6): 629
- Arnórsson S, Axelsson G, Saemundsson K (2008). Geothermal system in Iceland, Jökull, 58: 269-302.
- Blake DH (1970). Geology of the Álfafjörður volcano, a Tertiary volcanic centre in south-eastern Iceland. Sci. Iceland. 2: 43-63
- Björnsson A, Saemundsson K, Einarsson P, Tryggvason E, Grönvold K (1977). Current rifting episode in North Iceland. Nature. 266: 318-323.
- Hardarson BS, Fitton JG, Ellam RM, Pringle MS (1997). Rift-relocation - a geochemical and geochronological investigation of a palaeo-rift in NW Iceland, Earth Planet. Sci. Lett. 153: 181-196.
- Harðarson BS, Godfrey Fitton J, Árni Hjartarson (2008). Tertiary Volcanism in Iceland. Jökull.
- Burchardt S, Gudmundsson Á (2009). The infrastructure of Geitafell volcano, Southeast Iceland. In: Thórdarson, Th., Self, S., Larsen, G., Rowland, Höskuldsson, S.K. (eds.), Studies in volcanology: The Legacy of George Walker. GSL on behalf of IAVCEI publications. 349-369.
- Einarsson M (1991). Temperature conditions in Iceland 1901-1990. Jökull. 41: 1-19.
- Fridleifsson GÓ (1983a). The geology and the alteration history of the Geitafell Central Volcano, southeast Iceland. University of Edinburgh, Grant Institute of Geology, PhD thesis. Pp324.
- Fridleifsson GÓ (1983b). Mineralogical evaluation of a hydrothermal system. Geothermal Resources Council, Trans. 7: 147-152.
- Flóvenz ÓG, Saemundsson K (1993). Heat flow and geothermal processes in Iceland. Tectonophysics. 225: 123-138.
- Jakobsson SP, Gudmundsson MT (2008). Subglacial and intraglacial volcanic formations in Iceland. Jökull. 58: 179-196
- Neuhoff PS, Fridriksson Th, Arnórsson S, Bird DK (1999). Porosity evolution and mineral paragenesis during low-grade metamorphism of basaltic lavas at Teigarhorn, eastern Iceland. Am J. Sci. 299: 467-501.
- Pálmason G, Saemundsson K (1974). Iceland in relation to the Mid-Atlantic Ridge. Annual Review Earth Planet. Sci. 2: 25-50.
- Saemundsson K (1979). Outline of the geology of Iceland. Jökull 29: 7-28.
- Saemundsson K (1980). Application of geology in geothermal research in Iceland (in Icelandic with English summary). Náttúrufræðingurinn, 50(3/4): 157-188.

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