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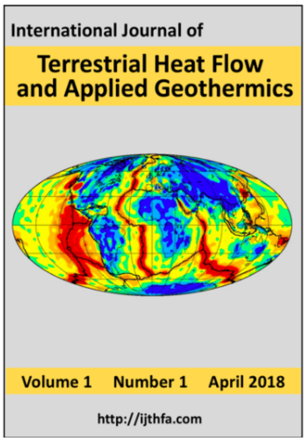

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Temperature Gradient Measurements in Hydrothermal Areas of Georgia

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Abstract

The project uses results of temperature measurements in shallow boreholes to determine the geothermal gradients for a selected set of wells in Georgia. The hydrothermal flow in the Caucasus region driven by ongoing tectonic activities causes a varying temperature field that impedes determination of stable temperature gradients. Conventional temperature logging provides only a snapshot of the temperature distribution in a well. Therefore, the methodology adopted in this study is based on continuous stationary measurements with up to eight temperature sensors fixed at different depths in the wells. Temperature measurements have been performed in 14 wells using thermometers with resolving power of 0.01 K. The temperature field was recorded during periods ranging from 16 hours to 4 days. This practice of measurements enabled detection of thermal effects of fluid flows within the selected set of boreholes. Considering the 14 wells that were selected for this study, eight showed signs of stability in temperature increase versus depth and the remaining seven wells revealed signs of instability due subsurface fluid flows.

1. Introduction

Georgia has been described (Melikadze and Tsertsvadze, 2010) as a country of many high potential sources of geothermal energy, which has been partly used since ancient times. Hot springs resorts, industry involved with processing, local heating systems, and greenhouses are some of the major areas of geothermal energy usage. As the result of all the research that has been done since 1970 including all of the exploration drilling and sampling, 44 geothermal heat deposits have been confirmed that prove the fact that Georgia is rich in geothermal resources. According to initial estimations, the amount of power of these resources reaches up to 420 megawatts. It is worthwhile mentioning that the water inside of most of the current medium depth geothermal wells located in Georgia (50 in total) indicates temperatures in the range from 40°C to 60°C; most of them in the non-operational state and none of them is used for the purpose of electrical power generation. It has been stated (Melikadze and Tsertsvadze, 2010) that not only any significant growth in utilization of this energy has yet occurred but also, sadly, only small parts of the identified resources are used, despite the fact that it could remarkably improve the economic condition of the country. It can be assumed that the hydrothermal aquifers can partially contribute to solve the current energy problem in Georgia. The urban center of Tbilisi with a population of 1.5 million inhabitants could be a center with the most feasible use of the heat production from these aquifers due to its multilateral usage and close access to the hydrothermal potential.

Therefore, it is very important to search and investigate the geothermal potential of Georgia by in-situ well temperature measurements implemented in various water wells. The analysis of the resulting data is a practical step to extend the database of the geothermal potential.

In this study, temperature measurements have been carried out in shallow wells to determine their temperature gradient. The hydrothermal flow in the Caucasus region driven by ongoing tectonic activities causes a varying temperature field that impedes the determination of stable temperature gradients. The methodology applied for this project is based on continuous measurements with up to eight temperature sensors fixed at different depths in the well.

Buachidze (1979) investigated the temperature distribution in the Earth's crust of the western Caucasus and the Black Sea region. Investigations carried out in 33 boreholes for the search of geothermal potential revealed a constant regular pattern in temperature gradient distribution and the thermal conductivity of the subsurface. The gathered data was the basis needed to derive generalized temperature profiles for certain tectonic regions. Deep boreholes (> 3.5 km), which reached the base of the sedimentary layers, were used to measure temperatures and to determine the corrected heat flow density applying thermal conductivity values for different temperatures and pressures. The common temperature interval at the base of the sedimentary layers covering most of the territory was about 100 to 200°C.

2. Methodology

Measurements were implemented in 14 different wells in order to determine thermal gradient throughout the depth and also to investigate the stability of temperature increase with depth. Each of these 14 wells is named after the city, village or area where these are located. The locations of these wells are distributed throughout Georgia, covering different regions of this country as indicated in Figure 1. Green dots in the map refer to the wells that are characterized by thermal gradients resulting from long-term constant and stable increase of temperature versus depth. The red dots represent wells that indicate thermal gradients resulting from unstable temperature variations versus depth caused by subsurface water flows.

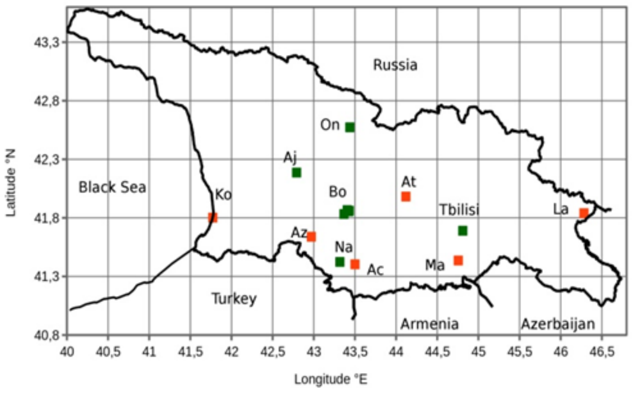

Figure 1 - The distribution of investigated boreholes in Georgia. Green dots represent wells with stable increase of temperature versus depth and red dots indicate the presence of wells with variable temperature gradients.

The names, related borehole numbers, the depth to the deepest sensor, the lithology of the surrounding rock layers of these wells, and the duration of measurement are compiled in Table 1. The wells marked with green background in the table are characterized by stable increase of temperature versus depth.

While conventional temperature logging provides only a snapshot of the temperature distribution in a well, continuous stationary measurements have been applied with up to eight temperature sensors installed at different depths in the well. Measurements have been performed in all 14 wells with the instrument designated as "LogBox-multiT" (www.geotec-instruments.com). The temperature field was recorded over periods of 16 hours to 4 days. This type of measurements enables detection of water flow within the monitored boreholes. The measurements were done by a maximum of eight sensors, all attached to one cable, fixed at a certain depth. The last sensor (sensor 8) was either at the bottom of the well, if its depth is less than 100 m, or at a depth of 100 m. The distance between neighboring sensors is 14.2 m.

Table 1 - Properties of the assessed boreholes.

Name of wells	**#**	**Depth of last sensor (m)**	**Main lithology**	**Duration (h)**
Akhaltsikhe (Az)	1	100	Sandstone, Andesite-basalt, Basalt, argillite sandstone, volcanic rocks	20
Akhalkalaki (Ac)	2	100	Basalt	23
Borjomi 47 (Bo)	4	90	Sandstone	23
Borjomi 67 (Bo)	5	80	Sandstone	18
Borjomi 70 (Bo)	6	90	Sandstone, Quartz–feldspar-bearing sandstone	19
Borjomi 102 (Bo)	7	95	Sandstone	23
Kobuleti (Ko)	8	85	Basalt	24
Lagodechi (La)	9	20	Clastic limestone	16
Marneuli (Ma)	10	50	Tuff	44
Nakhalakevi (Na)	11	100	Sericite-bearing clay shale	24
Oni (On)	12	90	Volcanic (mostly basalt) and volcano-sedimentary rock	62
Ateni/Ormotsi (At)	13	35	Light gray sandstone	95
Tbilisi	14	90	Dolerite-Sedimentary and volcano-sedimentary rock, Sandstone	46
Ajameti (Aj)	15	90	Limestone	47

3. Results and discussion

Among the 14 wells that were used to measure the temperature gradient versus depth, eight showed signs of stability in temperature increase versus depth. The remaining six wells showed short term instability due to subsurface water flows affecting certain sensors. Table 2 compiles the calculated temperature gradient of each well. The wells with stable temperature increase are marked with green background. The quality of the temperature gradients is marked as "+++", "++", "–+", and "––" meaning "good", "partially-good", "barley-acceptable", and "bad", respectively.

A good quality thermal gradient is characterized by a stable or monotonic temperature increase, without any local decrease with depth. However, a partially good gradient, as indicated in Table 2, has one or two sensors that has temperatures lower than the values recorded at the sensors above. The evaluation as "barley-acceptable" and "bad" gradients is based on more negative thermal gradients between neighboring sensors. In cases, where the thermal gradients are evaluated as bad or partially good, a data modification was implemented by excluding those sensors measuring lower values in comparison with their neighboring one above. We observed that wells that indicate higher amounts of acceptable thermal gradients show a more stable behavior in temperature increase versus depth.

Table 2 - Temperature gradients of the wells classified according to the stability of the temperature increase versus depth.

No.	Well name	Quality	Gradient (K/m)
#1	Akhaltsikhe (Az)	− +	0.0147
#2	Akhalkalaki (Ac)	− +	0.0022
#4	Borjomi 47 (3/2)	++	0.0410
#5	Borjomi 67	+++	0.0502
#6	Borjomi 70 (3/1)	+++	0.0271
#7	Borjomi 102	+++	0.0769
#8	Kobuleti	− −	0.00002
#9	Lagodechi	− +	0.0202
#10	Marneuli	− +	0.0077
#11	Nakhalakevi	+++	0.1218
#12	Oni	+++	0.0744
#13	Ateni/Ormotsi	−+	0.0141
#14	Tbilisi	+++	0.1148
#15	Ajameti	+++	0.0420

Among the wells with stable temperature gradients the one named Nakhalakevi (#11) indicates the highest gradient with value of 121.8 mK/m followed by the Tbilisi well (#14) with value of 114.8 mK/m. In spite of the recent stable thermal gradient, the impact of seismic/tectonic, man-made, meteorological and tidal factors has been demonstrated during temperature monitoring of several years (Buntebarth, Chelidze and Melikadze, 2005).

Among the wells in the Borjomi area, which has been famous for its mineral water and hot water springs for a long time, “Borjomi 102”, i.e. well #7, indicates the highest thermal gradient with 76.9 mK/m. A comparison of temperature profiles from Borjomi wells through depth can be seen in Figure 2. The temperature gradient increases strongly in the uppermost few tens of meters because the mean surface temperature is constant independent of elevation above sea level. These temperature profiles have been interpreted as indicating up flow of hydrothermal fluids. The Borjomi region is an area for mineral water extraction, where the pumping wells have been selected according to their productivity. For this reason, hydrostatic pressure is variable in the corresponding aquifers, which leads to unstable flow conditions in this hydrothermal area.

A complex hydrogeological situation with interactions between different aquifers results in local variations of the thermal gradient. The uppermost Middle Eocene volcano-clastic sequence is several thousand meters thick and is an aquifer of meteoric water which flows from high to lower regions (Zhukova, Melikadze and Dovgal, 2010). This water migration is dependent on the precipitation and can superpose the recorded temperature, so that a seasonal variation can occur. The infiltration of hot thermal water from greater depths with its origin in the Upper Cretaceous to Lower Paleocene carbonate sequence occurs near fault zones where up flows can occur. This ascending water increases the thermal gradient in the Borjomi region.

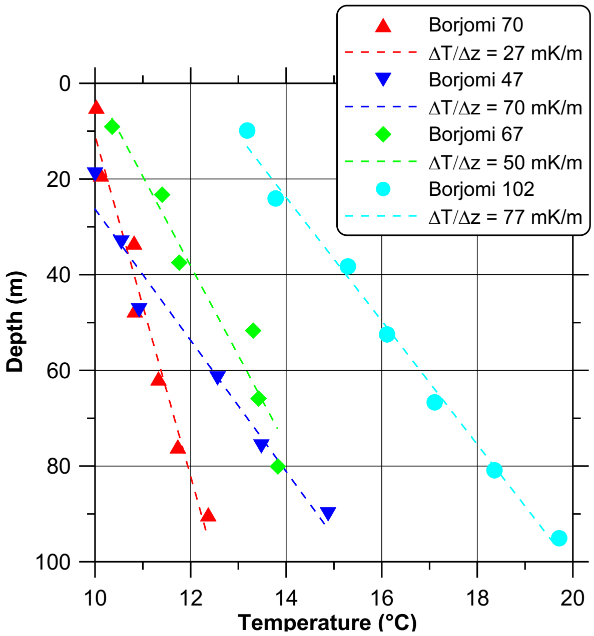

Figure 2 - Temperature variation versus depth in wells at the Borjomi region.

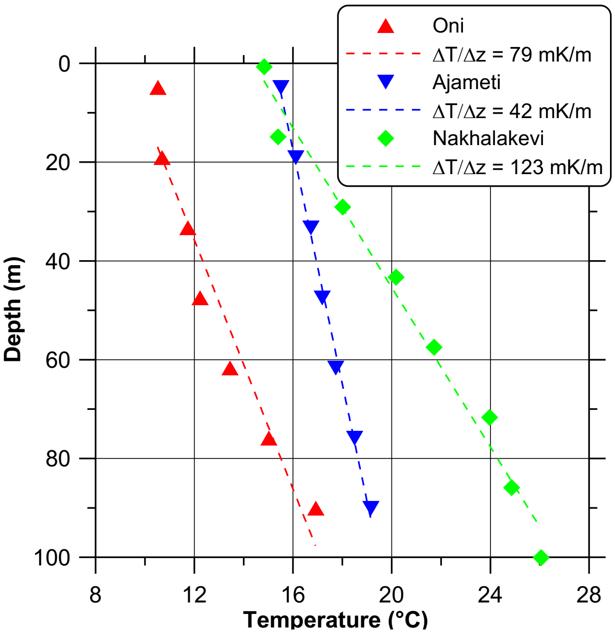

Figure 3 - Temperature profiles in wells at Oni (On), Ajemeti (Aj), and Nakhalakevi (Na) with stable geothermal gradients.

Temperature profiles of some other wells with stable increase of temperature versus depth are shown in Figure 3. The well Ajameti (#15) indicates a behavior without any hydrothermal activity. At Oni (#12) and Nakhalakevi (#11) wells, the hydrothermal contribution to the thermal condition of the subsurface can be observed by an increase of thermal gradient close to the surface. Nevertheless, the gradient seems to be apparently constant at greater depths.

Two examples of unstable thermal gradients are shown in Figure 4 with the wells of Kobuleti (#8) and Akhalkalaki (#2). Horizontal water flow, which is indicated by a temperature maximum, is suspected at a depth of 60 m in the Kobuleti well and at about 70 m in the Akhalkalaki well. The amount of injection seems not to be high. If these single values are excluded, an average annual mean surface temperature can be extrapolated and indicates a value between 13.5 and 14°C for the Kobuleti well.

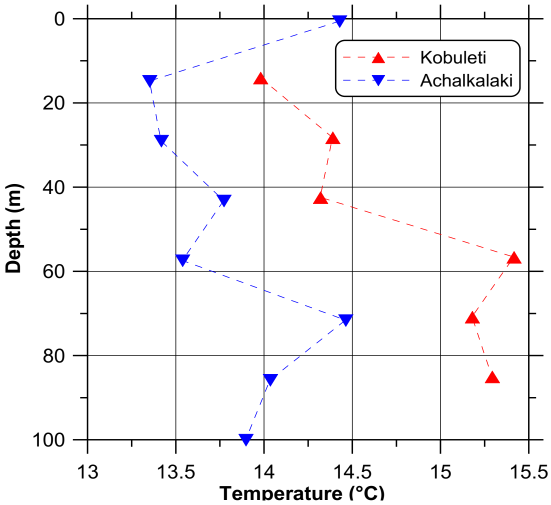

Figure 4 - Temperature profiles in the wells Kobuleti (Ko) and Achalkalaki (Ac) do not enable the determination of geothermal gradients due to temperature instability.

The sensors at Ateni (#13) could not penetrate deeper than 35 m. Therefore, the gradient is influenced by the seasonal surface temperature variation which penetrates down to 20 m with an amplitude of approximately 0.01 K.

Since the main purpose was to investigate change of temperature versus time, and not only depth-related variations, most of these measurements were made during long time intervals, extending from 16 hours to four days.

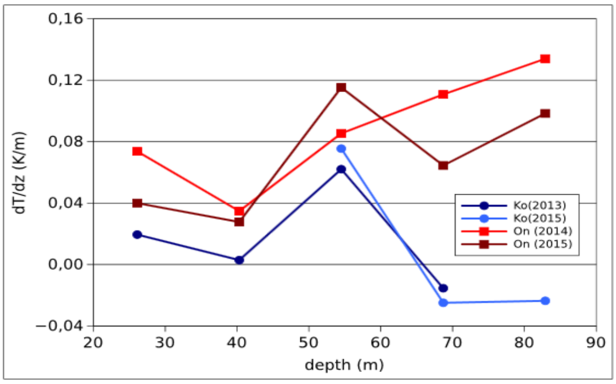

Figure 5 - Thermal gradient variation with depths in Kobuleti and Oni wells, recorded during different years of monitoring.

Additional records, available for wells at Kobuleti (#8) and Oni (#12) from 2013 to 2014, are shown in Figure 5. A nearly constant water injection between 50 and 60 m can be observed in the Kobuleti well. The water injection into the Oni well indicates some variation with time. The general increase of gradient at the Oni well can be explained by a thermal water injection at a depth greater than 85 m. During 2015, a change is observed with an additional injection at a depth between 50 and 60 m. These records demonstrate variability of the temperature field in regions with strong hydrothermal activity.

4. Conclusions

Temperature measurements have been carried out in 14 water wells, situated in various areas of Georgia. Eight wells showed signs of stability in temperature increase versus depth while the other six wells indicated instability due subsurface water flows affecting the sensors. Within the limited time range of measurements, stable thermal gradients were observed in the four Borjomi wells (#4, #5, #6, #7), and the wells at Nakhalakevi (#11), Oni (#12), Tbilisi (#14), and Ajameti (#15). Because of tectonic activity in the Caucasus region, the hydrostatic pressure field in wells can vary either continuously or suddenly. Comparing all wells with stable temperature gradients, the one at Nakhalakevi (#11) indicated the highest value with 121.8 mK/m, followed by the Tbilisi well (#14) with 114.8 mK/m. The six wells with unstable temperature gradients are at Akhaltsikhe (#1), Akhalkalaki (#2), Ateni (#13), Kobuleti (#8), Lagodechi (#9), and Marneuli (#10). Wells with higher values of thermal gradients show a more stable behavior in temperature increase versus depth. This means that the thermal water inflow is high and not very sensitive to pressure variation in the aquifer. Numerous hot sulfuric water springs, which indicate a high potential for geothermal resources at shallow depths, are known in the city of Tbilisi. A well in the Botanical Garden of Tbilisi is actively used to provide geothermal energy for green house heating systems. Among the wells in the Borjomi area, which has been famous for its mineral waters and hot water springs for a long time, "Borjomi 102", i.e. well #7, indicates the highest thermal gradient, with a value of 76.9 mK/m.

5. Acknowledgments

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