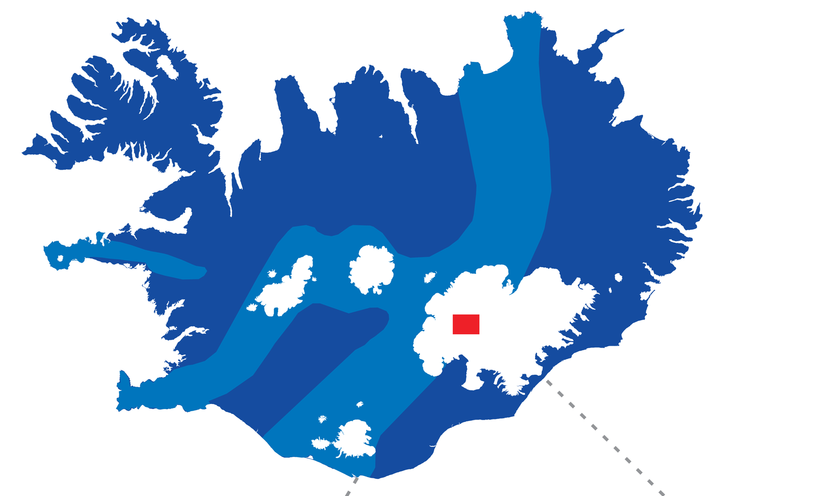
LOTEM-resistivity survey of subglacial high-temperature geothermal field, Grímsvötn, in SE-Iceland



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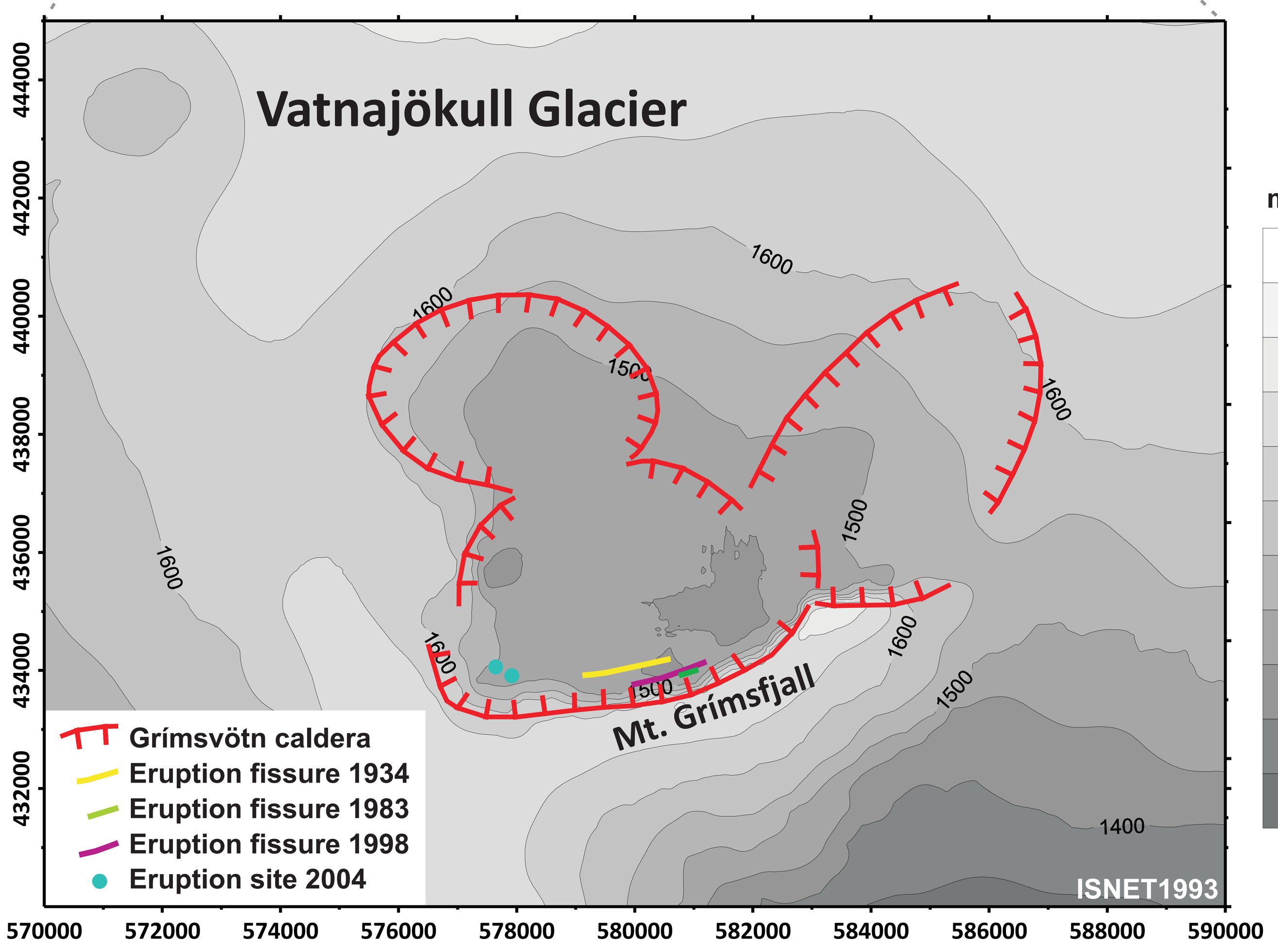
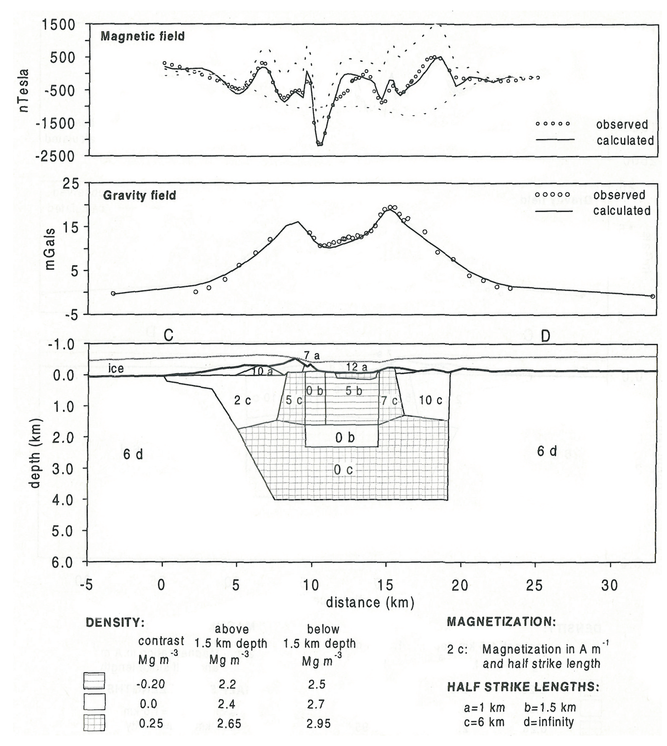
Introduction

Deep resistivity surveys have greatly improved the understanding of the inner and deep nature of volcanic high-temperature geothermal systems. In this study the Long Offset Transient Electro-Magnetic (LOTEM) method will be used to map the spatial extend and depth span of resistivity anomalies within the Grímsvötn geothermal system, located in the glacier Vatnajökull. Resistivity methods have the advantage of being highly sensitive to temperature in comparison with other geophysical methods. Exceptionally high heat output has been ongoing for centuries in Grímsvötn (e.g. Björnsson, 1988), making it an enigmatic geothermal area. Electromagnetic methods have until now not been used in Grímsvötn. The application of such methods would offer important new information on the behaviour of geothermal areas.

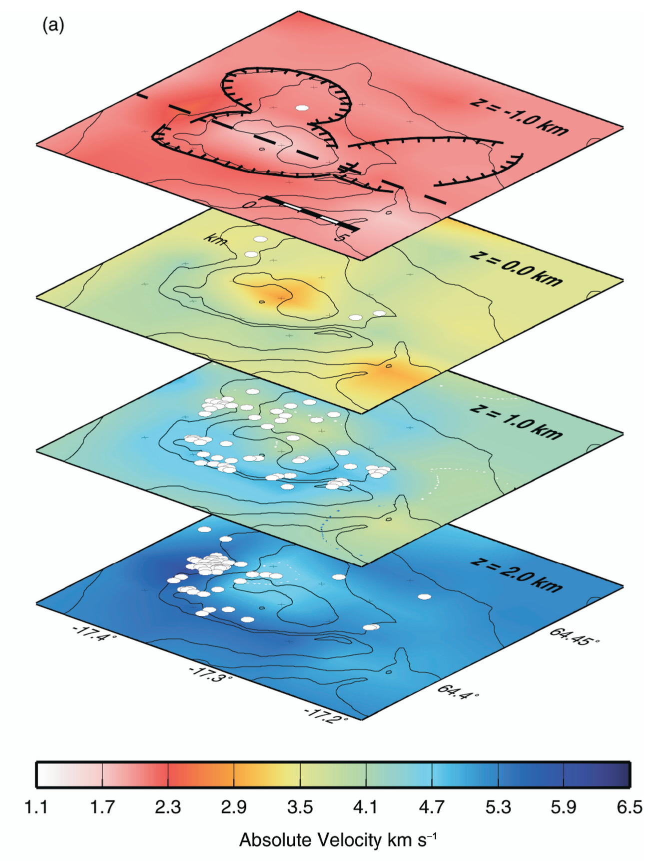


Grímsvötn is the most active volcano in Iceland in terms of eruption frequency, with over 60 known eruptions in the last 800 years (Larsen et al., 1998). The volcano is mostly covered by 300-600 m thick ice but the bedrock topography has been mapped with radio-echo soundings (Björnsson and Einarsson, 1990). Using the ice as calorimeter the thermal output of the area has been estimated 2000 - 4000 MW (Björnsson and Gudmundsson, 1993), showing that it is one of the most powerful geothermal areas in the world.

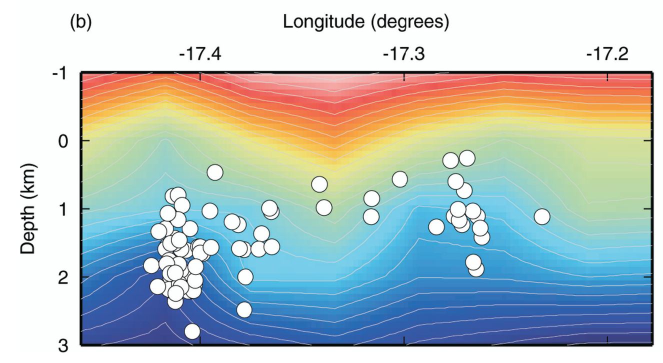
Existing data



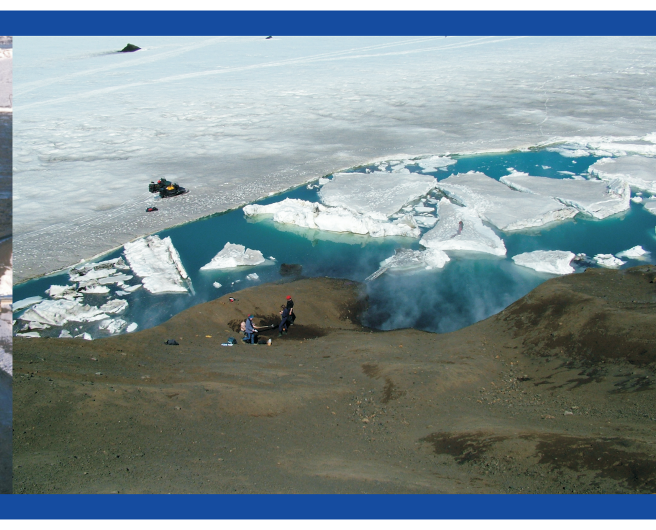
From Gudmundsson and Milsom, 1997



Seismic studies suggest that a magma chamber is located under the Grímsvötn caldera at 3-4 km depth (Alfaro et al., 2007), see figure to right. Gravity survey suggests a much larger high-density, probably intrusive body in the upper crust under the volcano (Gudmundsson and Milson, 1997), see figure above. GPS geodetic studies also support the existance of magma chamber (Sturkell et al., 2003).



From Alfaro et al, 2007



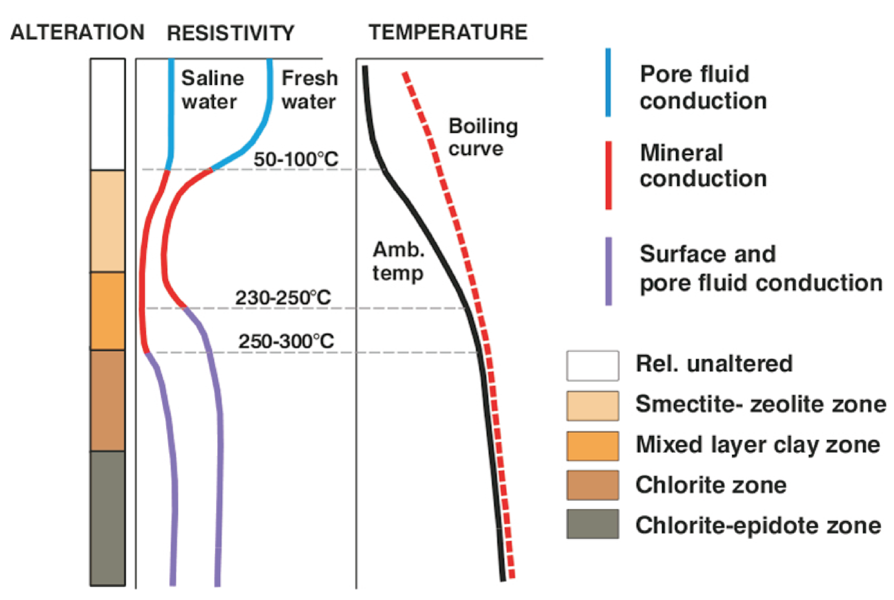
Resistivity

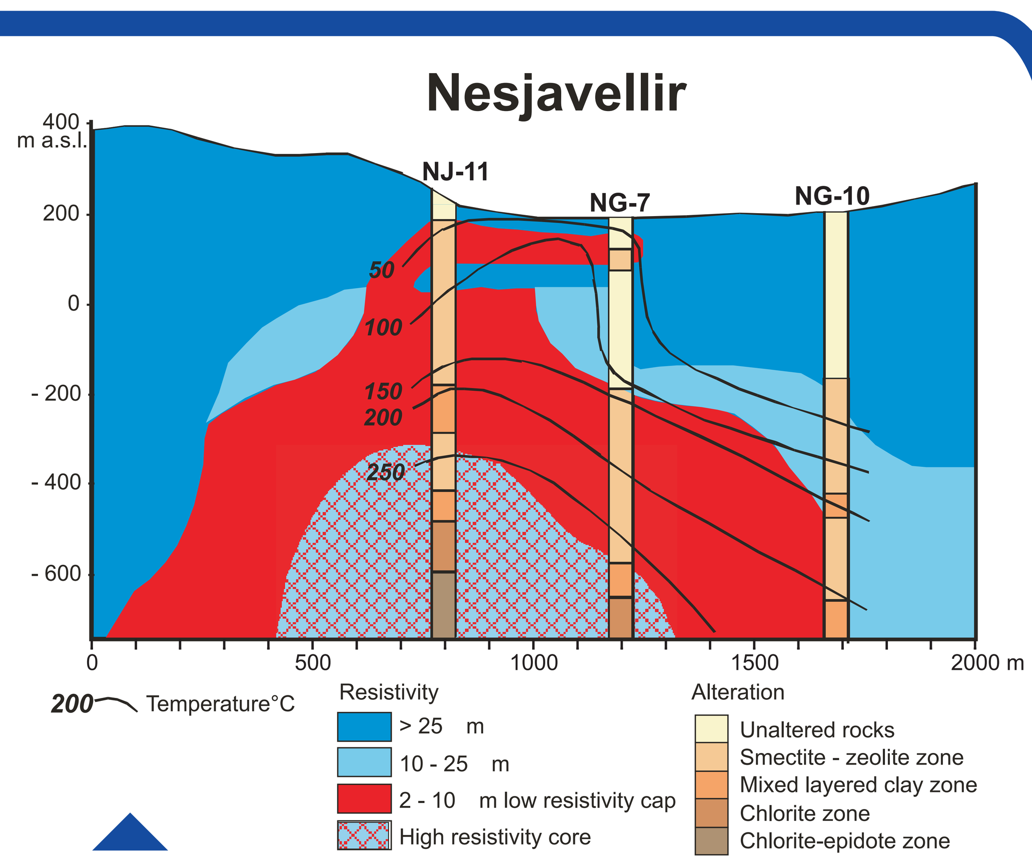
Extensive surveying by resistivity methods (mainly central-loop TEM) has shown that the high-temperature geothermal systems in the basaltic rocks of Iceland have a very distinctive and diagnostic resistivity structure in the upper most kilometer. The resistivity is mainly controlled by alteration mineralogy (Árnason. et al, 2000).

Cold unaltered rocks outside the geothermal system have high resistivity. At about 50°C alteration set in and between 100°C and 230°C aggressive alteration is present with conductive alteration minerals (smectite and zeolites). At temperatures higher than 240°C the conductive alteration minerals are replaced by resistive minerals (chlorite and epidote) and the rocks become resistive again.

The resistivity structure of the high-temperature systems is therefore characterised by a low resistivity cap and an underlying resistive core. If cooling has not taken place, the low resistivity cap reflects temperatures between 100°C and 230°C and the resistive core temperatures higher than 240°C. If cooling has taken place the alteration and the resistivity structure prevails, so the resistivity is a sort of a maximum thermometer.

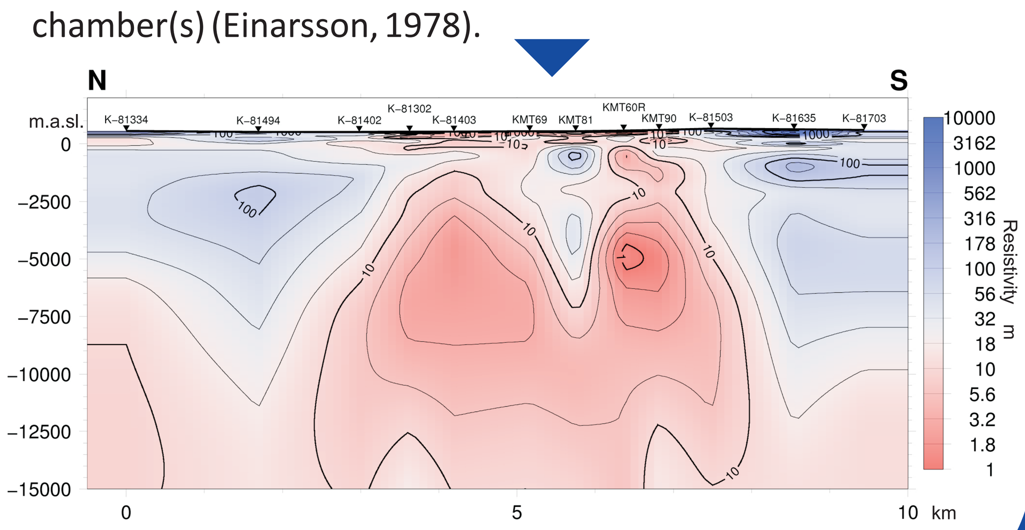
From Flóvenz et al, 2005





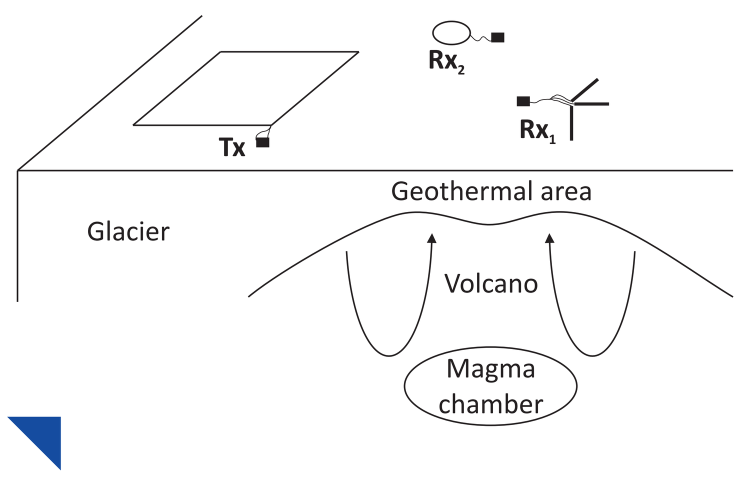
A simplified resistivity cross-section from Nesjavellir geothermal field, SW-Iceland (from Árnason et al., 1987). The zones of dominant alteration minerals are shown and temperature in nearby wells. The resistivity structure correlates fairly well with the alteration mineralogy.

Recent deep resistivity survey in Krafla area, by joint application of TEM and MT, have shown deep conductors under the geothermal system with the top at about 2.5-3 km depth (Árnason et al., 2009). A resistivity profile through the centre of Krafla geothermal field is shown below. The deep conductor rise up in the centre and the tops coincide with S-wave shadows observed during the Krafla fires and interpreted as magma chamber(s) (Einarsson, 1978).



Layout, processing

The survey will be carried out by laying a large loop (1km x 1km) of wire on the glacier (**Tx**). About 15A square wave will be transmitted into the loop. Switching the current in the loop will change its magnetic field which in turn induces currents in the ground. The three components of the transient secondary magnetic field from these currents will be measured by standard MT recording systems (**Rx$_1$**) and new TEM-receiver from Geonics (**Rx$_2$**).



The loop will be placed about 15 km away from Grímsvötn and the transient magnetic field recorded on a dense net in the central area. In order to illuminate the sub-surface resistivity structure from different directions, at least two different source locations will be used.

The recorded time series will undergo advanced signal processing (de-convolution, filtering and stacking). The data will be interpreted in terms of the subsurface resistivity structure by highly advanced three dimensional (3D) inversion code. The resulting 3D resistivity model will be interpreted jointly with other existing geophysical data from Grímsvötn, such as gravity and seismic (active and passive) to make a conceptual model of the Grímsvötn volcano and its high-temperature geothermal system and their inner structure.

Expected outcome

Deep resistivity surveys have greatly improved the understanding of the inner and deep nature of volcanic high-temperature geothermal systems. The unique situation in Grímsvötn, being covered by glacier and hence having a colorimeter makes it very interesting to study further. Studying its resistivity structure and knowing its thermal output gives an opportunity to estimate the total thermal output of other high-temperature systems.

The main objectives of a LOTEM survey of Grímsvötn are:

- To map the spatial extend and depth span of resistivity anomalies within the Grímsvötn geothermal system for comparison with other high-temperature geothermal systems
- To map the location and extent of magma bodies in the uppermost 3-5 km of the crust under the volcano
- To assess the thermal release from a pristine geothermal system for comparison with other geothermal systems under full exploitation

References

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Acknowledgement

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