



## **FINAL REPORT**

**The Hengill geothermal reservoir.  
Evaluation of subsurface geological data**

Project ID: 09-02-005

Coordinator: Hjalti Franzson / Iceland GeoSurvey

Start date: 1.1.2010

Duration: 12 months

Partners: Iceland GeoSurvey  
Reykjavík Energy  
University of Iceland

## 1 Project summary

*The purpose of the project was to start developing a comprehensive model of the Hengill high-temperature area, and to train six geothermal students in geothermal research with special emphasis on sub-surface geology. Five of the projects involved detailed mapping of the geothermal system, each of them combining borehole data from three relatively closely spaced drillpads. This included stratigraphic model, hydrothermal alteration and formation temperature, geological connection of permeability and evolution of the geothermal system deduced from alteration. This evaluation was followed by that each student taking on a study of more specialized nature. The special studies included the progressive alteration of olivine and pyroxene, sulphide mineralogy, clay mineralogy, and geochemical signature of the Hengill subsurface stratigraphy. The sixth project included a preliminary work on the drillhole data but with a major contribution of Sr isotope study in epidote formed in the geothermal system. I consider the results of these projects of high standard and success. Not only have they established a much better view on the diverse character of the geothermal system at Hellisheiði, but have also given a guideline to new methodology in the geothermal studies. Equally successful is the result of the advanced training given to the graduate students (where five out of six graduated with a MSc. degree) in the processing of various kinds of borehole data towards the development of a conceptual model of a geothermal system. They are now capable to undertake a specialized research on geothermal aspects of reservoirs.*

*The grant provided by GEORG was initiated the 1<sup>st</sup> of January 2010 for the duration of twelve months and earmarked for the students salaries for the execution of their special projects which were a part of the master projects. The plan was to finish the subsurface geothermal mapping in May 2010, the specialized projects and the submission of the MSc manuscripts by the end of 2010. The five dissertations were successively defended during the time interval from May 2011 to April 2012. The reasons for some delays in timetable of projects are mainly due to; workload in other projects, MSc projects becoming more ambitious than originally planned and malfunctions of laboratory equipment. These resulted in increased financial participation of Reykjavik Energy and Iceland GeoSurvey, and also by extra time of the students themselves. The main outcome were very high standard masters theses which contribute significantly to the conceptual model of the geothermal system.*

## 2 Project Management

*The main part of the project was to study the cutting samples by petrographic and XRD methods, handle and combine the various borehole data and develop a geological conceptual model. These methods have been developed at ISOR. An ISOR project management was during this stage. The specialized project was done at the University of Iceland, and the project management was left there in the hands of the supervisors there and the respective students. One reason for the expansion of the projects was different views of ISOR and UI on which part of the research should be the primary consideration. This is a long standing difference of approach between applied and academic institutions. In retrospect this dilemma should have been resolved at the onset of the projects.*

### 3 Student involvement

The project is based on the work of six students, who made this the basis for their MSc. dissertations. All but one finished with a MSc. degree.

Steinþór Níelsson

Helga Margrét Helgadóttir

Sandra Ósk Snæbjörnsdóttir

Sveinborg Hlíf Gunnarsdóttir

Gísli Örn Bragason

Theodóra Matthíasdóttir (did not finish)

### 4 Publications and disseminations

The students publicised their project work widely at conferences, workshops and meetings. They benefitted greatly by participating in the PhD days which was partly financed by Georg.

*Helga Margrét Helgadóttir 2011. Berggrunnur og jarðhitaummyndun Gráuhnúkakerfis á sunnanverðu Hengilssvæðis. Meistararitgerð, Jarðvísindadeild, Háskóli Íslands, 185 bls.*

Helgadóttir, H.M., Snæbjörnsdóttir, S.Ó., Níelsson, S. Gunnarsdóttir, S.H., Matthíasdóttir, T., Harðarson, B.S., Einarsson, G.M. and Franzson, H. 2010. Geology and hydrothermal alteration in the reservoir of the Hellisheiði high temperature system, SW-Iceland. WGC, Bali. Reviewed paper. Electronic publication.

*Helga Margrét Helgadóttir, Sandra Ó. Snæbjörnsdóttir, Sveinborg H. Gunnarsdóttir, Steinþór Níelsson 2011. Fyrirlestur og abstrakt; Hellisheiði, ummyndun og jarðhitakerfi. Orkuveita Reykjavíkur, dagsráðstefna 01.12.2011 um jarðhitakerfið í Hengli*

*Helga Margrét Helgadóttir 2012. Hydrothermal dissolution of olivine and pyroxene in the Hellisheiði geothermal field, SW-Iceland. 30<sup>th</sup> Nordic Geological Winter Meeting. Short abstract.*

EGPD 2010 – Potsdam, Þýskalandi – PhD day í febrúar 2010 – Poster: Helga Margrét Helgadóttir og Sveinborg Hlíf Gunnarsdóttir: Geological 3D model of the Hellisheiði geothermal field

Vorfundur JFÍ 2010 – Poster: Helga M. Helgadóttir, Sandra Ó. Snæbjörnsdóttir, Steinþór Níelsson og Sveinborg H. Gunnarsdóttir: Gerð þrívíddarmóðels af jarðhitasvæði Hellisheiðar

Kynningardagur hjá GEORG, október 2011: Poster: Helga Margrét Helgadóttir: The dissolution of olivine and pyroxene in the Hellisheiði geothermal field, SW-Iceland

PhD-day í Reykjavík 2011 - póster -Hellisheiði high temperature field, SW-Iceland – geology, hydrothermal alteration and permeability structures, Helga M. Helgadóttir, Sandra Ó. Snæbjörnsdóttir, Steinþór Níelsson og Sveinborg H. Gunnarsdóttir.

*Steinþór Níelsson 2011. Jarðfræði og ummyndun í jarðhitakerfinu við Hverahlíð á Hellisheiði. Meistararitgerð, Jarðvísindadeild, Háskóli Íslands. 208 bls.*

Níelsson S., and Franzson, H. 2010. Geology and hydrothermal alteration of the Hverahlíð HT-system, SW-Iceland. Proceedings World Geothermal Congress, Bali, Indonesia. Reviewed paper. Electronic publication.

*Steinthor Nielsson 2012. Evolution of the Hengill Volcanic Centre, SW-Iceland. 30<sup>th</sup> Nordic Geological Winter Meeting. Short abstract.*

Steinþór Níelsson, 2011. Geology and hydrothermal alteration of the Hverahlid HT-system, SW-Iceland. Paper presented at the Autumn meeting of the Icelandic Geological Society, Reykjavik, Iceland.

Steinþór Níelsson, 2011. Geology and hydrothermal alteration of the Hverahlid HT-system, SW-Iceland. Paper presented at the Scientific Drilling in the Nordic Countries workshop, Soultz, France.

Geology and Hydrothermal alteration of the Hellisheidi HT-system, SW-Iceland. Paper presented at the annual Iceland GeoSurvey conference, Reykjavik, Iceland.

Steinþór Níelsson, 2010. Geology and Hydrothermal alteration of the Hellisheidi HT-system, SW-Iceland. Paper presented at the European Geothermal PhD-Day 2010, Reykjavik, Iceland.

Steinþór Níelsson, 2011. Geology and hydrothermal alteration of the Hverahlid HT-system, SW-Iceland. Paper presented at Geothermal Research Group Conference, Reykjavik, Iceland.

*Sandra Ósk Snæbjörnsdóttir 2012. Jarðfræði og jarðhitaummyndun við vesturjaðar sigdældar Hengils. Meistararitgerð, Jarðvísindadeild, Háskóli Íslands, 242 bls.*

*Sandra Ósk Snæbjörnsdóttir 2012. Structure and composition of clay minerals in the Hellisheiði Geothermal Field, SW-Iceland. 30<sup>th</sup> Nordic Geological Winter Meeting. Short abstract.*

[EGPD 2011 – Reykjavík, Íslandi – PhD day í mars 2011 – Poster: Sandra Ósk Snæbjörnsdóttir, Sveinborg Hlíf Gunnarsdóttir, Steinþór Níelsson og Helga Margrét Helgadóttir: Hellisheiði high temperature field, SW-Iceland – geology, hydrothermal alteration and permeability structures](#)

Leirkúrs í Gautaborgarháskóla og verkefni í tengslum við sérverkefni vor 2009 -greinagerð: Clay analysis in well HE-17 in the Hellisheiði geothermal area. Comparison of different methods, ÍSOR-09053, Sandra Ó. Snæbjörnsdóttir, Sigurður Sveinn Jónsson

Sumarskóli norrænu eldfjallastöðvarinnar 2010 - póster og abstrakt: Intrusions and permeability at Mt. Skarðsmýrarfjall, Hellisheiði Geothermal Field, SW-Iceland, Sandra Ó. Snæbjörnsdóttir

Sumarskóli norrænu eldfjallastöðvarinnar 2011 - abstrakt - Structure and composition of clay minerals in the Hellisheiði High Temperature field, SW-Iceland, Sandra Ó. Snæbjörnsdóttir, Björn Harðarson, Hjalti Franzson, Níels Óskarsson

PhD-day í Pisa 2012 - abstrakt og póster - Structure and composition of clay minerals in the Hellisheiði High Temperature field, SW-Iceland, Sandra Ó. Snæbjörnsdóttir, Björn Harðarson, Hjalti Franzson, Níels Óskarsson

*Sveinborg Hlíf Gunnarsdóttir 2012. Jarðfræði og ummyndun í nágrenni Reykjafells á Hellisheiði. Meistararitgerð, Jarðvísindadeild, Háskóli Íslands. 217 bls.*

*Sveinborg Hlíf Gunnarsdóttir 2011. Fyrirlestur og abstrakt; Hellisheiði, Jarðlög, innskot og vatnsæðar. Orkuveita Reykjavíkur, dagsráðstefna 01.12.2011 um jarðhitakerfi í Henglinum*

*Sveinborg Hlíf Gunnarsdóttir 2012. Opaque minerals in geothermal well HE-42, Hellisheiði, SW-Iceland. 30<sup>th</sup> Nordic Geological Winter Meeting. Short abstract.*

*Gísli Örn Bragason 2012. Strontium isotope shift in clay minerals, epidote and geothermal fluid in the Hellisheiði Geothermal Field, SW-Iceland. 90 ECTS thesis submitted in partial fulfillment of a Magister Scientiarum degree in Geology, 59 p.*

*Gisli Örn Bragason, K.Grönvold, N.Óskarsson, G. Sigurðsson, G.Sverrisdóttir, Hjalti Franzson 2012. Strontium isotope shift in geothermal alteration minerals and geothermal fluid in the Hellisheiði Geothermal field: Implications for water-rock interaction. 30<sup>th</sup> Nordic Geological Winter Meeting. Short abstract.*

## 5 Cost statement

*This project was financially somewhat complicated. Initial plan was that it would be financed by Reykjavik Energy for the main part and GEORG would finance the special project at the University of Iceland lasting three months. The project became more ambitious and both parts expanded. This expansion was financed by ISOR and Reykjavik Energy. The project has two kinds of prices; the main ISOR part was priced as a commercial project but with a significant cut off which was ISOR's contribution. ISOR financed the rest of the project, when Reykjavik Energie's tolerance level was reached, but subsidized by the GEORG funding. The project of the sixth MSc student, Gísli Örn Bragason, only involved ISOR and Reykjavik Energy to a minor extent as it was accomplished predominantly at the University of Iceland. The financial statement therefore only involves the GEORG contribution, which financed three months work. In the original grant application the University of Iceland estimated about half a man-month for each student (250.000/student) and an equipment cost 150.000kr/student. This is summed up to a total UI cost of 2.00.000 kr.*

*If the cost of the project (59.183.000 kr) is compared to the project plan as described by GEORG (37.850.000 kr), it became about 56% more expensive. However, if compared with the original cost estimate of 73 m kr in the grant application (19,5 m kr Georg and 53 m kr other sources) it becomes more realistic.*

Consortium: Iceland GeoSurvey, Reykjavik Energy, University of Iceland																
Name of Project: The Hengill geothermal reservoir. Evaluation of subsurface geological data																
ISK '000	Year	2010/2012														
	Month	1	2	3	4	5	6	7	8	9	10	11	12	Total Y1		
<b>Financing</b>																
<b>GEORG funding</b>														4.500.000	8%	
Reykjavik Energy														31.093.255		
Iceland GeoSurvey														19.251.042		
University of Iceland														2.000.000		
Other national compet. grants														0		
Other intern. Grants, e.g. FP7														0		
Other sources (e.g. Philanthropic)														0		
<b>Total other financing</b>														0	0%	
<b>Total financing</b>														59.183.173		
<b>Operational Costs</b>																
Average Personnel Costs		Unit cost												Man-months		
<i>Participant:</i>																
401 Helga Margrét Helgadóttir														11.428.763	11,4	
402 Steinþór Níelsson														13.504.638	14,5	
403 Sandra Ósk Snæbjörnsdóttir														10.673.512	12,2	
404 Theodóra Matthíasdóttir														6.147.613	2,6	
405 Sveinborg Hlíf Gunnarsdóttir														12.189.771	15,1	
Supervision														2.338.876	2,0	
Gísli Örn Bragason														900.000	3,0	
University of Iceland														2.000.000	0,0	
														0	0,0	
<b>Total</b>			0	0	0	0	0	0	0	0	0	0	0	0	59.183.173	61
<b>Operational exp.</b>																
														0		
														0		
														0		
<b>Total</b>														0		
<b>Contracted services</b>																
														0		
														0		
														0		
<b>Total</b>														0		
<b>Travel expenses</b>																
														0		
														0		
														0		
<b>Total</b>														0		
<b>Others</b>																
														0		
														0		
														0		
<b>Total</b>														0		
<b>Total operational cost</b>			0	0	0	0	0	0	0	0	0	0	0	0	59.183.173	