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GeoInformation in Geothermal Development

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ABSTRACT

Geographic and location dependant data are very important, yet sometimes overlooked, at all stages of the development of geothermal fields. This data are at all scales, from global maps showing the distribution of geothermal activity in the world, to the very local scale of an individual borehole. The information is in itself valuable, but it can provide when combined more valuable information about the individual geothermal field.

Using mostly out-of-the-box software developed in geographic information science or in the oil & gas industry and adapting them to our purpose, we have powerful applications for analysis, as well as sharing information with colleagues and clients.

The purpose of this study is to identify and define categories (most of the major, and some of the minor) of geoinformation used in the geothermal industry as well as to discuss the importance of the spatial component of geothermal data and how we can combine data together spatially. As well as identifying and defining the categories of information, examples of geographic data at the regional scale will be shown, followed by a case study from a geothermal field under development where categories of geographic data discussed are combined to create a true three dimensional model of the geothermal system.

1. INTRODUCTION

In his famous paper, *A computer movie simulating urban growth in the Detroit region, Waldo Tobler* (1974) states what has since been accepted and believed to be the first, and only law of geography:

"Everything is related to everything else, but near things are more related than distant things. "

Although this statement might be stating the obvious, it lays a fundamental truth that is especially true in the geothermal industry. The geographic location is a very important attribute of all activities, events and "things" (Longley et. al. 2005) and geothermal resources and their utilization has therefore a double connection to geothermal information.

The concepts of geographic information, geographic information systems and geographic information science have many definitions, ranging from a container of maps in digital form to tools for analyzing geographic data. So everyone can have their own favorite definition (Longley et. al. 2005).

In this work the definition of the geoinformation in geothermal development are the data and information that the data can give us. For the purpose of this paper we define all data and information that can be related to a place as geographic information. This information can be at all resolutions and in all dimensions.

Data on geothermal resources and the development of geothermal systems has not been conceptualized as being geographic and is therefore often poorly defined as geographic entities. Commonly geothermal data has no metadata defined, and is derived from other sources. Here we try to identify these data collections, the purpose being to suggest a framework for geothermal information resulting in the complete definition of a geographic data for the geothermal industry.

Modern relational database systems (Oracle, Postgre, MySql and MS-SQL) are capable of storing both the geometrical and topological information needed when dealing with geographic data as well as normal tabulated information, such as wire line logs and other measurements. Relations between geographical locations and tabulated data are therefore easy to create (Rigaux et. al. 2002).

2. GEOTHERMAL INFORMATION

Whilst researching for this paper, it became apparent that defining geographical, geothermal information is not something that can be done in a short conference paper. Relevant Icelandic, European and international standards for geographic information do not specifically address the needs of the geothermal industry. Therefore we suggest the concept of geothermal information and outline that briefly.

Geothermal information is all information describing a geothermal resource: it's natural state, exploration and utilization. By taking into account all aspects of utilization of geothermal resource it serves as the basis for evaluating their sustainable use.

With this definition in mind it is obvious that a common framework for geothermal information is required. Such a framework for geothermal information needs to take into account the requirements of all the relevant participants the geothermal industry including financial data, measurements by geoscientists in the field, engineering design and reservoir monitoring. A project is being prepared in cooperation with the major players in geothermal research and development in Iceland, suggesting a framework for geothermal information.

Where no defined structure exists to manage geothermal information, experience, shows that relevant data can go missing or become unclear to users other than those that originally collected. This can be reduced significantly with a clear framework, relevant metadata and organized methods of storing geothermal data.

A consortium of some of the major participants in the Icelandic geothermal industry has been set up. Iceland GeoSurvey is a leading provider of geoscientific services to the geothermal industry, Orkustofnun the supervisory body, and Reykjavík Energy a leading company in geothermal utilization. On the completion of this project the flow of information within the industry should improve significantly. When the framework has been established it will become easier for smaller companies to gather all the information needed for geothermal development.

Framework like this takes time to implement. In the short run the framework would enable better management of information, but in the long run an organized framework will lead to more sustainable geothermal utilization. The framework also enables future scientists and decision makers to make better informed decisions based on structured information using the best data available.

As pointed out in the introduction, geothermal development occurs at a geographic location. Therefore a geographic angle is very helpful when organizing collections of geothermal information. The standards for geographic information that currently exist do not satisfy the needs of the geothermal industry. The proposed framework developed should enable easy interoperability of geothermal information, comply the standards laid out by the INSPIRE directive (2007/2/EC) and comply with the EU framework (2000/60/EC) for Community action in the field of water policy, whilst that does not take geothermal resources into account. The framework will also be based upon relevant ISO19000 standards.

On successful completion the framework for geothermal information will support:

- Strategic planners, laying out governmental plans for geothermal development.
- Monitoring bodies that oversee energy companies that collect data on geothermal resources and utilization.
- Energy companies compiling data for reservoir estimation.
- Consulting firms and institutions, where data are being processed.
- The public, as well formed and organized data are much easier to grant access to, understand and navigate.

As with all geographic information, geothermal information changes as we look at an area in a greater resolution. For example, a geographic point might describe a geothermal area on a low resolution topographic map, whilst at a high resolution map the same entity is described by a geographic area having distinct boundaries. Also in a traditional GIS environment a borehole is described using a point geographic feature. This is not very accurate as the entity borehole also has length and commonly also direction and inclination. Geologic and geophysical data acquired in a borehole therefore have an absolute 3D coordinate (x,y,z). A framework for geothermal information needs to take this into account.

A framework for geothermal information has to be interoperable, flexible and easy to use for it to be successful. At the same time it needs to indentify all the major attributes that one needs to make informed decisions. There are many approaches to conceptual management of information/data. There are two models that might work best in a framework for geothermal information. One approach might be similar to what is laid out by Anderson (1976). The system is hierarchical and numbered and increased level of detail is shown by adding a new number into the system. Another method is to use an object oriented approach. Then real world entities are modelled as objects, and their state is stored as attributes, for example in tables. Objects can be classified, and many hierarchical classes generated. Then the problem becomes that many of the most relevant attributes in geothermal development are very difficult to define as objects, for example elements such as temperature, pressure, electric resistivity and bedrock alteration. Those have to be defined as geographic fields. Therefore a framework for geothermal information has to be based on combinations of data modeling methods.

Metadata is very important in addition to all geographic data. Metadata is in its basic form structured information about the data that informs users on the nature of the data. There are levels of metadata, but in most relevantly it answers questions like: What is the data? When was the data collected? Why? Where? By whom? For what purpose? Metadata is an especially important factor when thinking about and working with geothermal information. For example, there are many different tools and reasons to run a temperature log in a borehole, there can be many boreholes on the same drill platform, perhaps that have different purpose. Therefore all collections of geothermal information has to have metadata embedded into its basic structure.

In the next sections examples of geothermal information will be given. The examples are intended to show what a framework for geothermal information should entail. Going through this at three different levels of detail and scale, here referred to as resolution, examples will be described in detail for each of the three resolution categories.

2.1 Small resolution geothermal information

Small resolution geothermal information is information on geothermal resources at a global to national scale. This information describes locations of geothermal fields, power plants, planning zones, major roads leading to the geothermal areas and related features. Attributes can be for example name, installed capacity or number of boreholes.

In addition small resolution geothermal information includes general data on geothermal utilization for a whole country. Information such as the number of people served, total production of electricity and hot water, for example, will be taken into account here.

Information here is sporadic, change is not frequent and then mostly attributes need to be updated. Here a geographic point is used to represent the location of a geothermal field and no additional details are shown to indicate features within the field cartographically. Figure 1 demonstrates this, showing the geothermal fields in Iceland.

2.2 Medium resolution geothermal geographic data

Medium resolution geothermal information is perhaps the most important category, as it is used to describe individual geothermal fields. At this scale a geographic point might represent the location of a borehole instead of describing the entire geothermal system.

At this resolution it is important to have access to hydrologic, geologic and geophysical information. All these play important roles when planning where to locate boreholes, and other manmade structures that are related to the development of the geothermal resource.

Medium resolution geothermal information includes all object types, defined in geographic information science.

Line features, are for example, geologic mapping of lineaments, wellpaths of deviated boreholes, pipelines and powerlines. Polygon features can be defined as geologic formations, borehole platforms and planning areas. Point features have briefly been indentified above; other point features are, for example, various sampling sites and surface manifestations.

The attributes of these are very different, yet they all have relations to each other. For example, attributes of a proposed wellpath are different from the attributes of an actual well.

In addition to objects there are some very important field parameters. A geographic field is where every location has a value of the same attribute. These are for example formation temperature, depth to ground water, electric resistivity, magnetic anomalies, depth to alteration and geothermal gradient. These are both two dimensional and three dimensional fields as some are extended down to the earth's crust. This leads to other sets of interesting problems having to do with how best to model, and share this information. This will be looked at in detail later in the paper.

Figure 2 is an example of medium resolution geothermal information, showing locations of boreholes and tectonic settings in the Hengill region SW Iceland.

High resolution geothermal geographic data

High resolution geothermal information is very detailed and as contrast to small and medium resolution geothermal information the information describes individual borehole, its path, and locations within the borehole. Figure 3 shows the wellpaths of boreholes in Hellisheiði and identifies aquifers in well HN-09.

On some occasions it might be necessary to carry out very detailed mapping work in a specific area. For example sometimes detailed temperature measurements are carried out in soil to understand the distribution of geothermal activity that is not visible to the naked eye. Measuring of flux of various gasses such as CO_2 are very detailed.

Attributes at this scale change significantly. High resolution geothermal information has to take into account changes that occur over time, such as the well top pressure and flow rates from boreholes. In addition high resolution geothermal information has to take into account various wireline measurements taken at different times for very different reasons. The attributes of a borehole do therefore vary ranging from simply being depth, completion date and width, to complex time series and variables obtained at certain depth in the borehole.

When working with measurements and observations from somewhere within a borehole it becomes important to know exactly where in a borehole the measurement was made. Using a wireline gyroscope inclination and azimuth of the borehole is measured and an actual 3D coordinated well path is then calculated using this data and the measured depth. This gives an absolute location in the borehole, which measurements and observations can be related to. Therefore a borehole has an absolute location where as collection of borehole data have a relative location. Figures 3 and 4 demonstrate this. In figure 3 the borehole is shown on a map. There the length of the line is the horizontal distance from the starting point, rather than the actual length of the borehole. In figure 4 however the same borehole is displayed as a three dimensional feature.

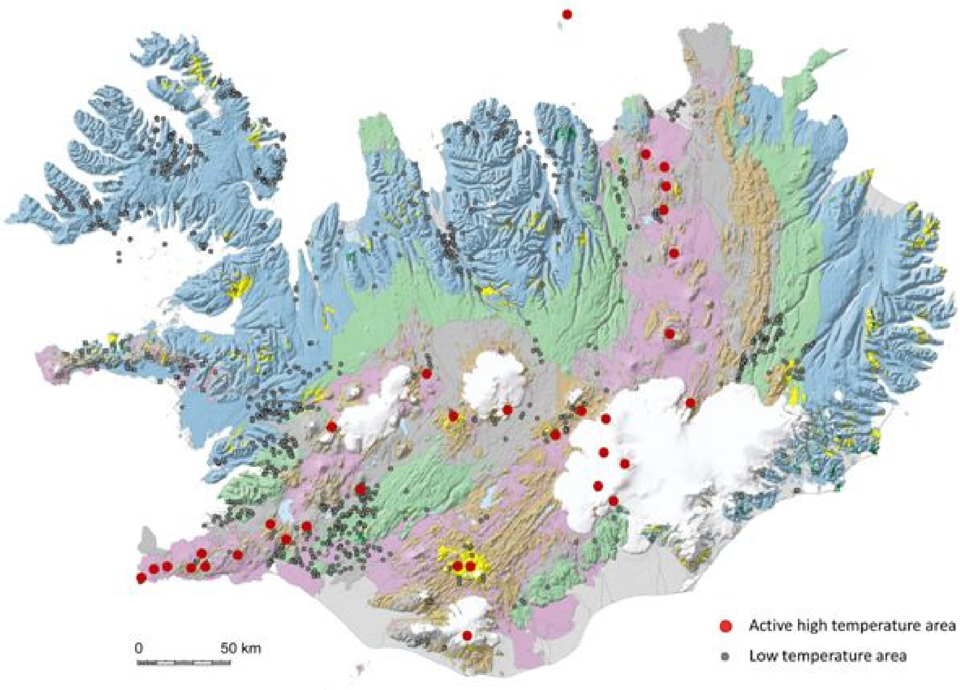

Figure 1. Geothermal fields in Iceland. Red dots show the locations of high temperature fields and back low temperature fields (Based on Jóhannesson and Sæmundsson 1999.),

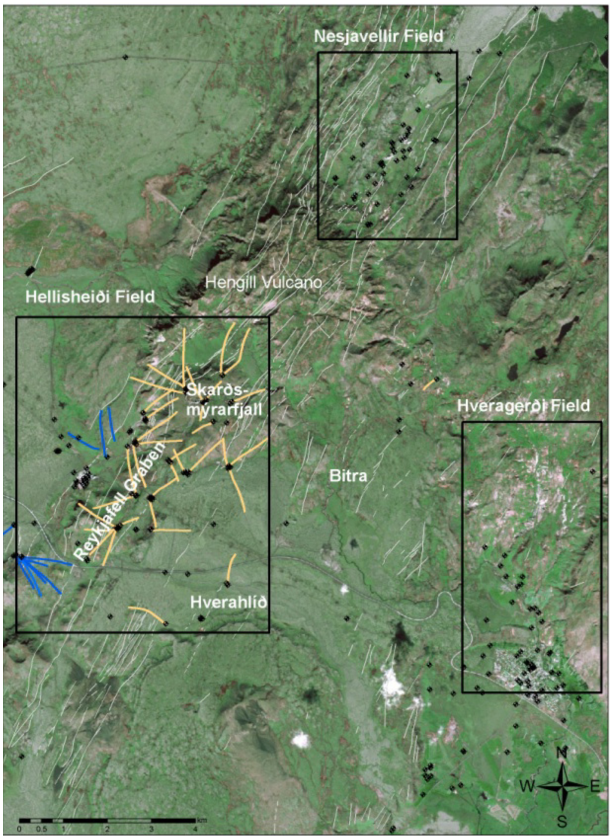

Figure 2. Medium resolution geothermal information displayed on a map. Example from Hellisheiði Iceland. Modified from Hardarson et. al. (2009).

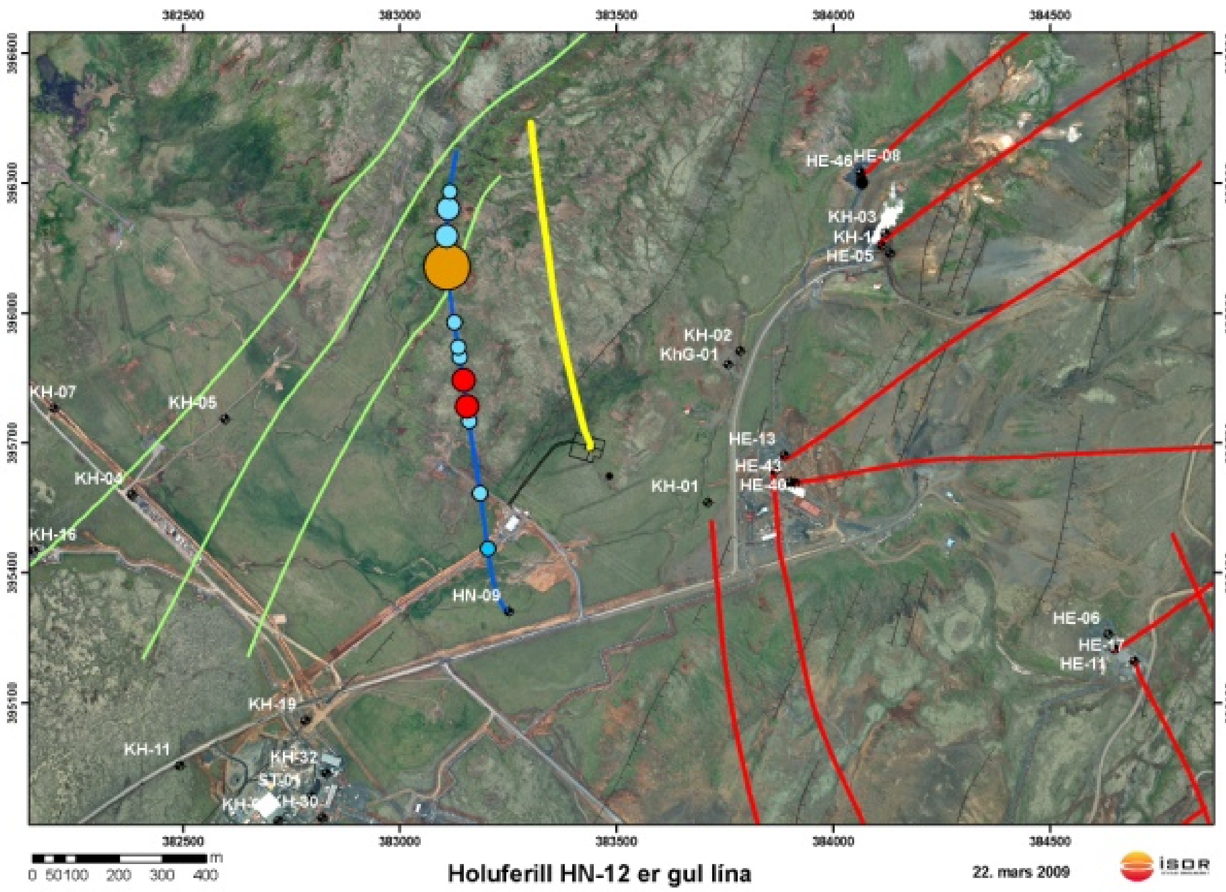

Figure 3. Aquifers in well HN-09 in Hellisheiði (blue, red and orange dots).

High resolution geothermal information is to some extent, fundamentally different from other geothermal information. The attributes collected are significantly different and in some cases the methods used to obtain the location are very different. But these all have in common that they can be modeled spatially and shared using mapping and geovisualization techniques. That will be discussed in the following chapters.

3. SPATIAL MODELING OF GEOTHERMAL SYSTEMS

The current analysis capabilities available in modern GIS systems can be very useful when working with geothermal information. For example add-ons to the ArcGIS software have been created to aid with decision making to locate regional scale geothermal resources (Noorollahi et. al. 2007, Noorollahi and Itoi, 2007 Noorollahi et. al. 2008 and Yousefi et. al. 2007). These studies show the potential for analysis geothermal information to aid in analyzing of geothermal information. Coolbough et. al. (2005) uses GIS techniques to create a geothermal map of the Western United States. Many other geothermal maps from many sites exist at various scales. Most recent maps are created using geographic information so much of the underlying GIS data exists. Framework for geothermal information has therefore to look at attribute information in more detail than the coordinate information.

Geothermal reservoirs are three dimensional in nature and the utilization adds the forth, time dimension. High resolution geothermal information has to be combined into statistical models, in all dimensions, using out-of-the-box software solutions e.g Hardarson et. al. 2009, Hardarson et.al, this issue, Níelsson & Franzson, this issue, Helgadóttir et. al. this issue, and Haraldsdóttir et. al. this issue. The approach is based upon using coordinated data, and then using advanced spatial interpolators, to connect between wells, surface and other geologic data. Our toolbox includes some excellent software tools. A geographic information system (ArcGIS) is used to collect and store topographic data, areal images, well information and surface geology. Some 3D visualization of geothermal fields has been developed in this software suite, and some 2D interpolations between well features. In 2008, our software toolbox was enhanced significantly with the addition of the Petrel software suite. As a result of the increased and more detailed modeling and analysis capabilities the need for well defined structure for the information the model has been clearly demonstrated.

For successful modeling of geothermal reservoirs and the utilization of geothermal systems four equally important parameters are important:

- High quality research data and field measurements,
- Software,
- Skilled and qualified staff and
- Structured, well organized geothermal information.

As a result of the significant increase in research and utilization of geothermal energy for generation of electricity in Iceland, during the last decade, the geothermal industry has grown. During this period a great attention has been given to the first three parameters as much very good data is being collected, analyzed and reported in research papers and other publications. Measurement instruments are constantly being improved, as well as the analysis techniques. The software tools are there, commercial tools have been developed for the oil and gas industry and within the research communities that can be adopted by the geothermal industry. The geothermal industry has many well qualified and skilled people within its ranks. What is missing is the structured standardized framework for geothermal information like the one proposed in this paper.

Having such a framework will enable much better understanding of geothermal resources and in return lead to informed discussions about geothermal recourses, their utilization and sustainable development.

4. SHARING GEOGRAPHIC GEOTHERMAL INFORMATION

A map is the classical way to relay spatial data. Many excellent geothermal maps exist but as well as some that are not as good. Geothermal maps can sometimes be complicated and the format is not good to show some of the more complex spatial features of a geothermal field. Therefore 3D animations can add that extra something. Figures 1-3, are examples of maps. Figure 4 is a screen shot from a 3D animation showing the same data as figure 3.

The obvious drawback of a map presentation of geothermal boreholes is the lack of the third dimension, as a borehole is extended down into the earth. A 3D representation of geothermal reservoirs is essential and therefore this added dimension, whit added complexity emphasizes the importance of well structured geothermal datasets.

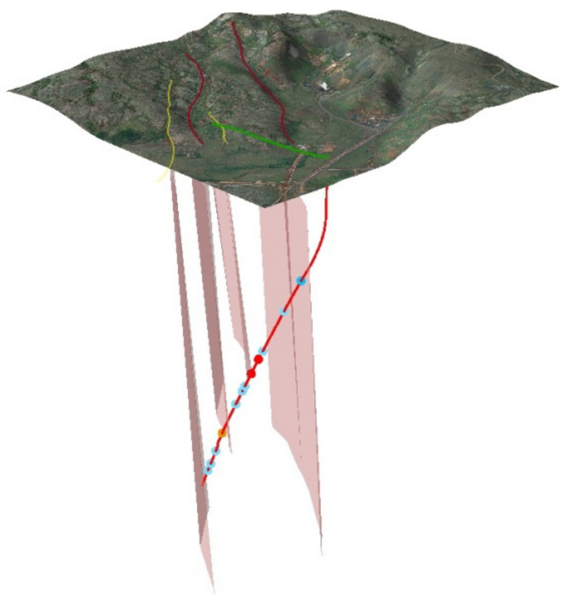

Figure 4. Screen shot from a 3D model showing well HN-09 in Hellisheiði.

Web mapping applications

Some map applications exist on the internet where geographic information about geothermal is available a map services (see www.gagnavefsja.is, www.natturuvefsja.is, http://www.geotis.de/ for example)

In addition to specialized thematic services some use Google Earth to make geothermal map data available, for example:

- A Googol of Heat Beneath Our Feet, that can be found at http://www.google.org/egs/,
- Web database of geothermal fluids in Switzerland http://www.crege.ch/BDFGeotherm/

These services are very good as the data is clear and well structured. Google Earth can serve as a tool for the geothermal industry to share information in an easy and a user friendly manner, tool that is widely distributed, and easy use to share information to a broader audience, without large investments in software development.

Web mapping applications have the tendency to be difficult to understand and navigate. This is partly caused by the software used to create those but also by the underlying data. Having a framework for geothermal information will enable easier sharing of geothermal information on maps, as 3D and 4D animation and in web mapping applications.

5. CONCLUSION

As the utilization of the renewable geothermal resource steadily increases as is the amount of valuable geothermal information collected. This information exists in all formats, ranging from printed reports, to textfiles and from spreadsheets to large database system. Information about geothermal resources is not organized in an interoperable, standardized manner. Whilst this is so, there is a great change that important data about geothermal resources will not be available to the people that need it when they need it.

All geothermal information has a spatial component; therefore a geographic information approach to all geothermal information is obvious. Having a framework will enable much better understanding of geothermal resources, make sure relevant data is collected and that the data is stored in an organized manner. Framework for geothermal information will enable new data analysis methods to be applied to geothermal data. In addition well structured data is much easier to share between geothermal experts and the wider public.

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