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The Value of Multidata Visualization in Geothermal Resource Assessment

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ABSTRACT

In exploration and subsequent management of geothermal resources a vast amount of data is accrued. This data can be from a variety of sources and times, ranging from rock cuttings collected during well drilling to surveillance temperature and pressure well logs taken years after drilling. At ÍSOR a large part of such measured data has been collected, stored and organized in relation databases, from both domestic and foreign geothermal fields. This centralization of data has allowed for the development of the VINNSLA-system, a program that allows the end-user an easy way to compare and contrast data from different sources and is used in integrated interpretation of data. The VINNSLA-system has been used, e.g., to estimate the undisturbed formation temperature and initial pressure of the reservoir of a geothermal system, and later to follow changes due to production from those systems. It has also been used to find the location of important feed zones using simultaneous visualization of downhole temperature data and spinner data, whether it is raw spinner data or data derived from spinner data such as downhole fluid velocity or mass flow. Along with aiding in analysis and interpretation, the VINNSLA-system also produces figures ready for publications in reports and papers.

1. INTRODUCTION

A well-structured relational database, while an excellent resource, requires a user to have a certain level of skill to use effectively. A user must know both the organization of the database and have knowledge of the SQL programming language. This can result in a user needing to spend a large amount of time crafting a query to access the relevant data, and risks the user getting an incomplete overview of the data. To remedy this and make it easier for an individual user to access relevant data, ÍSOR has developed the VINNSLA-system. The VINNSLA-system is a web application that provides a simple and powerful user interface to interact with the geothermal database at ÍSOR. This application lets a user access all the data stored in the database in a simple way, as well as providing tools to aid in analysis of the data.

Initially ÍSOR used an Oracle database system to store geothermal data. A variety of different single and multipurpose programs were used to simplify access to the database. These included scripts to retrieve and plot logging data, to create borehole well tracks and a web application to access data on chemical samples. The biggest application was the FORM-system, a web application that allowed the user to view information on boreholes and store logging data in the database. It also functioned as a management system for tracking logging instruments used by ÍSOR. These small single purpose programs, while being easier than using the database directly, had the downside of having the functionality scattered in different places. This made it difficult for users to know all the capabilities available to them.

In 2016 a decision was made at ÍSOR to switch from the Oracle database to a free open-source relational system, PostgreSQL. During this transfer it was also decided to restructure the database (Gunnarsdóttir (2020)). This was done to increase the amount of metadata and data, and to update the organization to better fit with newer techniques. Due to the extent of these changes the scripts and programs that interfaced with the Oracle database would all become deprecated. This made it necessary to either update these older programs or to create an entirely new system. The older programs were written in many different programming languages, and in some cases the original source code was not well documented or even unavailable. Therefor a decision was made to create a new system, VINNSLA (Icelandic for processing).

This system would be a single application. It would collect all the functionality of the different programs into a single application. The system would leverage the new structure of the database to show the connections between the different data stored in the database. It would be a web application using the older FORM-system as a blueprint, rather than a local application. The primary motivation for selecting an online application, rather than offline one, was to make it as simple as possible for a user to access the application. A central application would allow improvements and changes to the application to reach all users immediately and ensure that all users would be using the newest versions. To use the system a user simply needs a web browser and access to the web application site. This means that even a user in the field, e.g. at a drill rig, has access to the system so long as that user is connected to the internet.

2. THE VINNSLA-SYSTEM

2.1 Test case – chemical analyses

As a test case a user interface for the chemical part of the database was made. This user interface allowed the user to view and register information on different chemical sample. Figure 1 shows an overview page for a chemical sample. The user interface allows a user to easily search for samples based on different criteria, like location, concentration of a certain chemical, the sample collector or conditions at the sample site. The system also offers the possibility of exporting the information to files or tables.

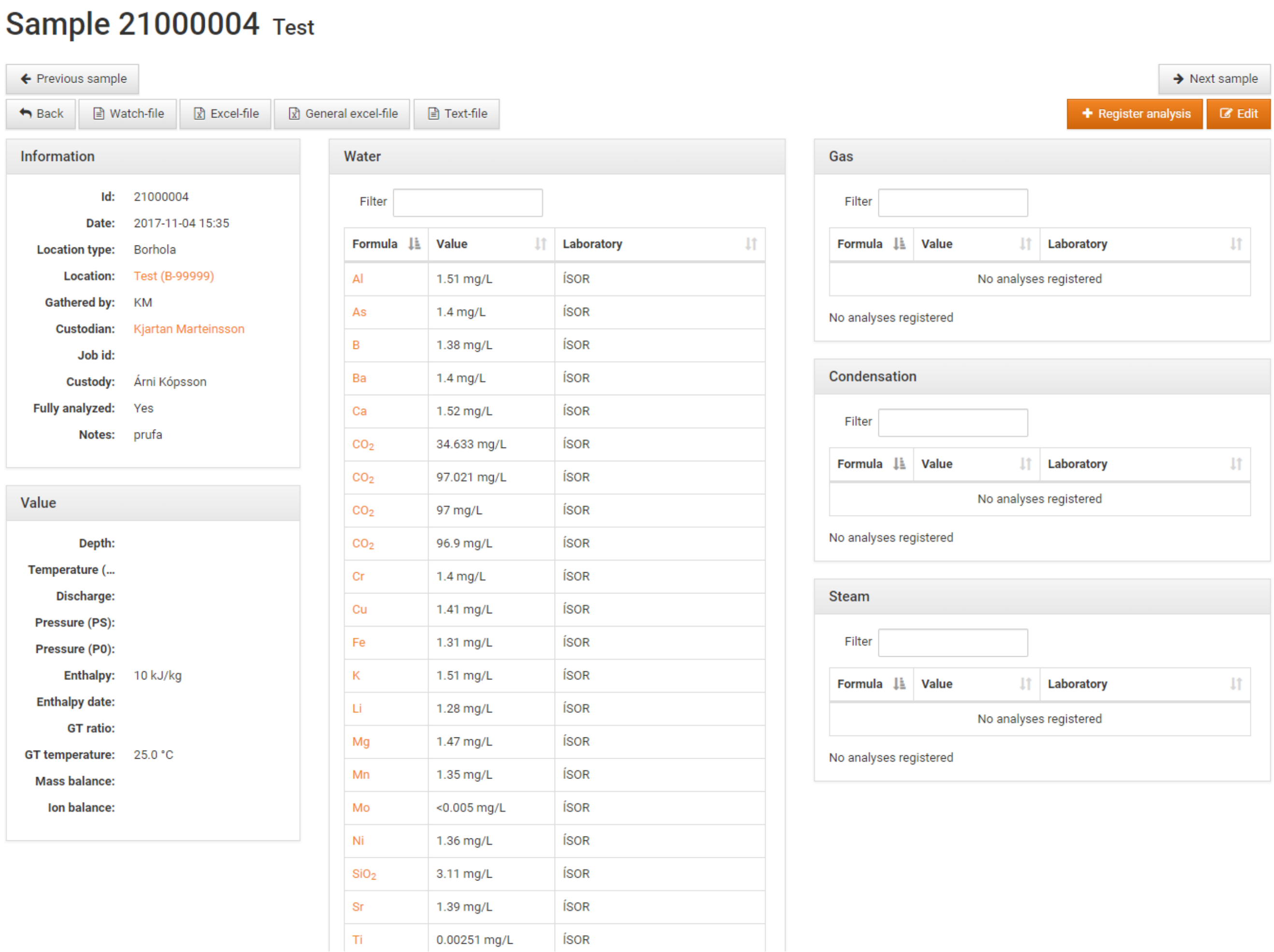


Figure 1. Overview of a chemical sample.

A tool was also created to dynamically plot the change in concentration for different components in samples collected at the same location, see Figure 2. This is made possible due to the structure of the database, where each component analysis is linked to a sample, and each sample is linked to a location. The user selects a location and then can choose which component to plot dynamically.

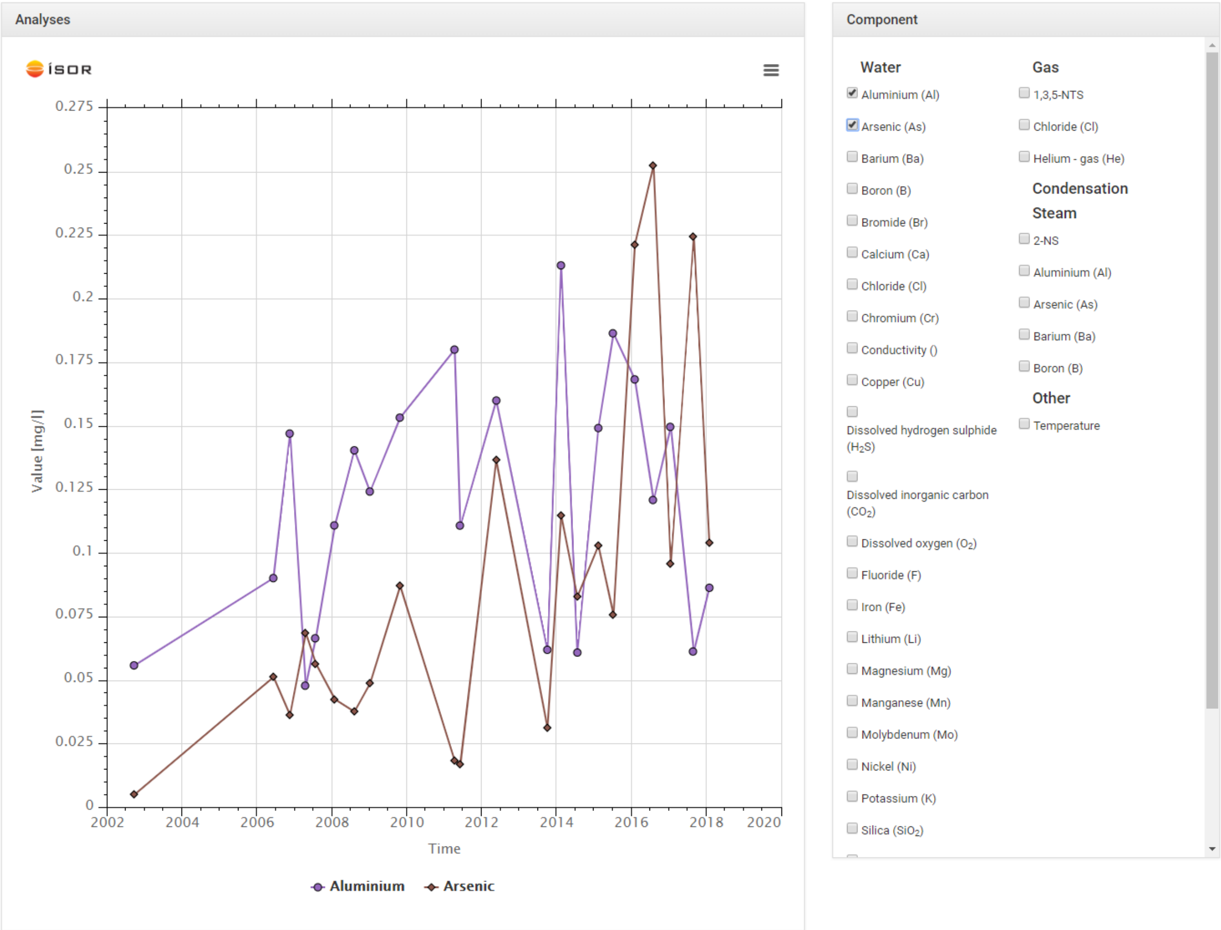


Figure 2. Concentration of a chemical in a single location as a function of time.

Building on the chemical section, similar sections were created for location data, logging data and instruments. As time has passed, more and more sections for different functionalities have been added to the system, including packages to analyze various types of data. Going over the entire functionality of the VINNSLA-system would take too long, so we will mention some of the larger programs that have been used to do multidata visualization before going into more concrete examples.

2.2 Locations

The location table can be considered the core of the ÍSOR geothermal database, and the same is true for the VINNSLA-system. Each registered location, e.g. a well or a natural spring, has an overview page. An example of a location overview page can be seen in Figure 3. The overview page enumerates all registered data connected to the location, includes listing all logs preformed at the site, each cutting sample and every chemical sample. For boreholes it also includes a visualization of the downhole well track and formation temperature and pressure curves. This allows a user to see and retrieve different data connected to a specific location in a simple way.

Like the chemical section, the location section has a search that allows the user to find relevant locations, see Figure 4. The main parameters to search on are the location name, number or type. It is also possible to perform more advanced searches using more parameters, like municipality, spatial coordinates or depth constraints.

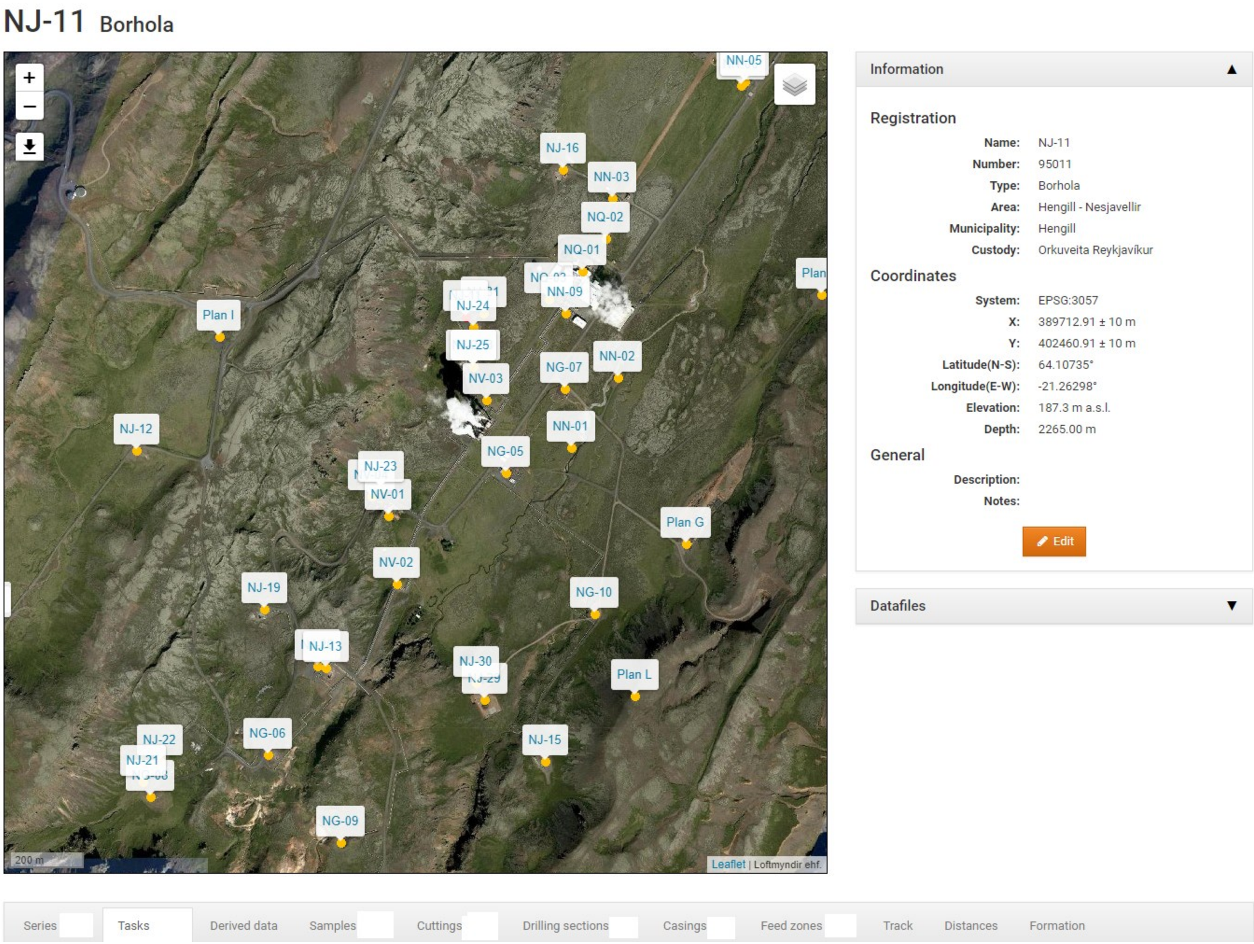
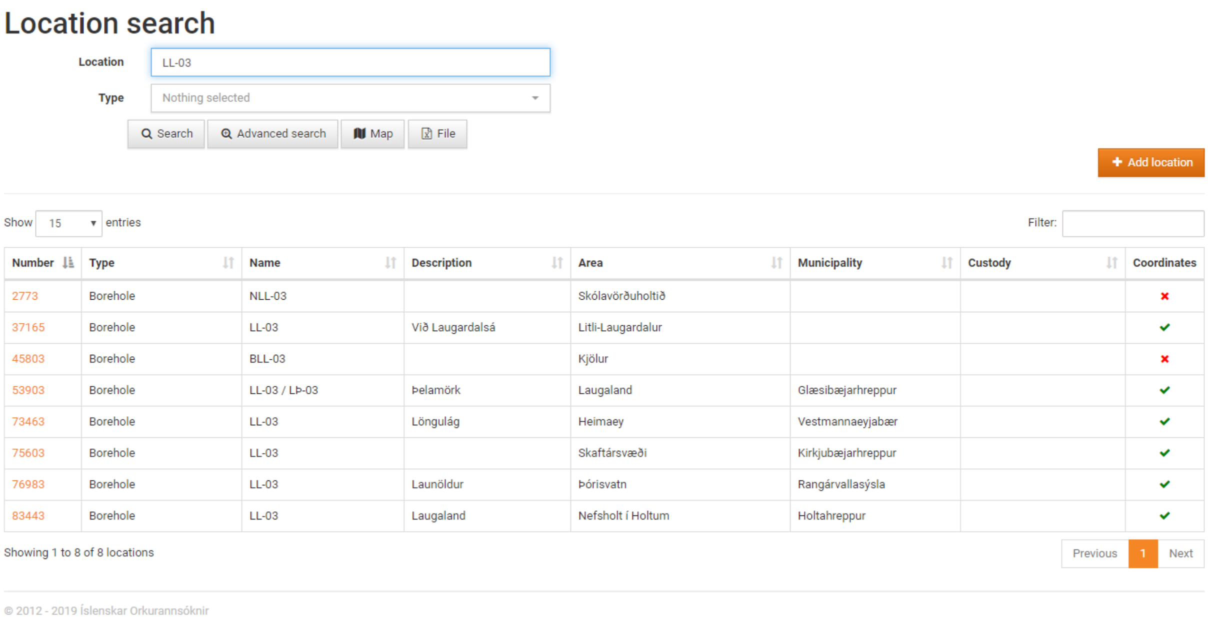


Figure 3. An example of the location overview page.



Number	Type	Name	Description	Area	Municipality	Custody	Coordinates
2773	Borehole	NLL-03		Skólavörðuholtið			✗
37165	Borehole	LL-03	Við Laugardalsá	Litli-Laugardalur			✓
45803	Borehole	BLL-03		Kjölur			✗
53903	Borehole	LL-03 / LÞ-03	Þelamörk	Laugaland	Glæsibæjarhreppur		✓
73463	Borehole	LL-03	Lönguláq	Heimaey	Vestmannaeyjabær		✓
75603	Borehole	LL-03		Skaftársvæði	Kirkjubæjarhreppur		✓
76983	Borehole	LL-03	Launöldur	Þórisvatn	Rangárvallasýsla		✓
83443	Borehole	LL-03	Laugaland	Nefsholt í Holtum	Holtahreppur		✓

Figure 4. Location search.

2.3 Measurements

Among the data on the location overview page is information on different logs and other measurements performed at the location. This measurement section allows the user to access detailed overview pages for each measurement, showing all metadata and plotting the actual data. It also has a tool to let loggers register new logs in the database. This means that loggers, after preforming a measurement, can quickly upload the logging data to the database. Other users then get instant access to any new measurement data that is registered, resulting in the time difference between logging and analysis being shortened. One tool in the VINNSLA-system to analyze borehole logging data is MÆLIMYNDIR. This package allows the user to dynamically create interactive plots from different well logs stored in the database. These can be different types of logs, temperature, pressure etc., and from different wells. In this way a user can, e.g. quickly plot the newest pressure logs from wells in the same general area or plot all temperature and pressure warm-up logs for a single well. These plots can be converted to image files and can easily be customized to fit the needs of the user. It is also possible to store the current plot and retrieve it later to add new data.

Figures 5, 6 and 7 show examples of plots created with the package. In Figure 5 not all the temperature measurements have been selected, and the casings have been added along with the formation temperature for the well. Figures 6 and 7 show how the package can be used to find the strongest feed zone in a well and the initial reservoir pressure at that feed zone. Figure 6 shows all the pressure log during heat up of the well, while Figure 7 shows how it is possible to zoom in and find the pivot point, i.e. the point where the pressure logs cross.

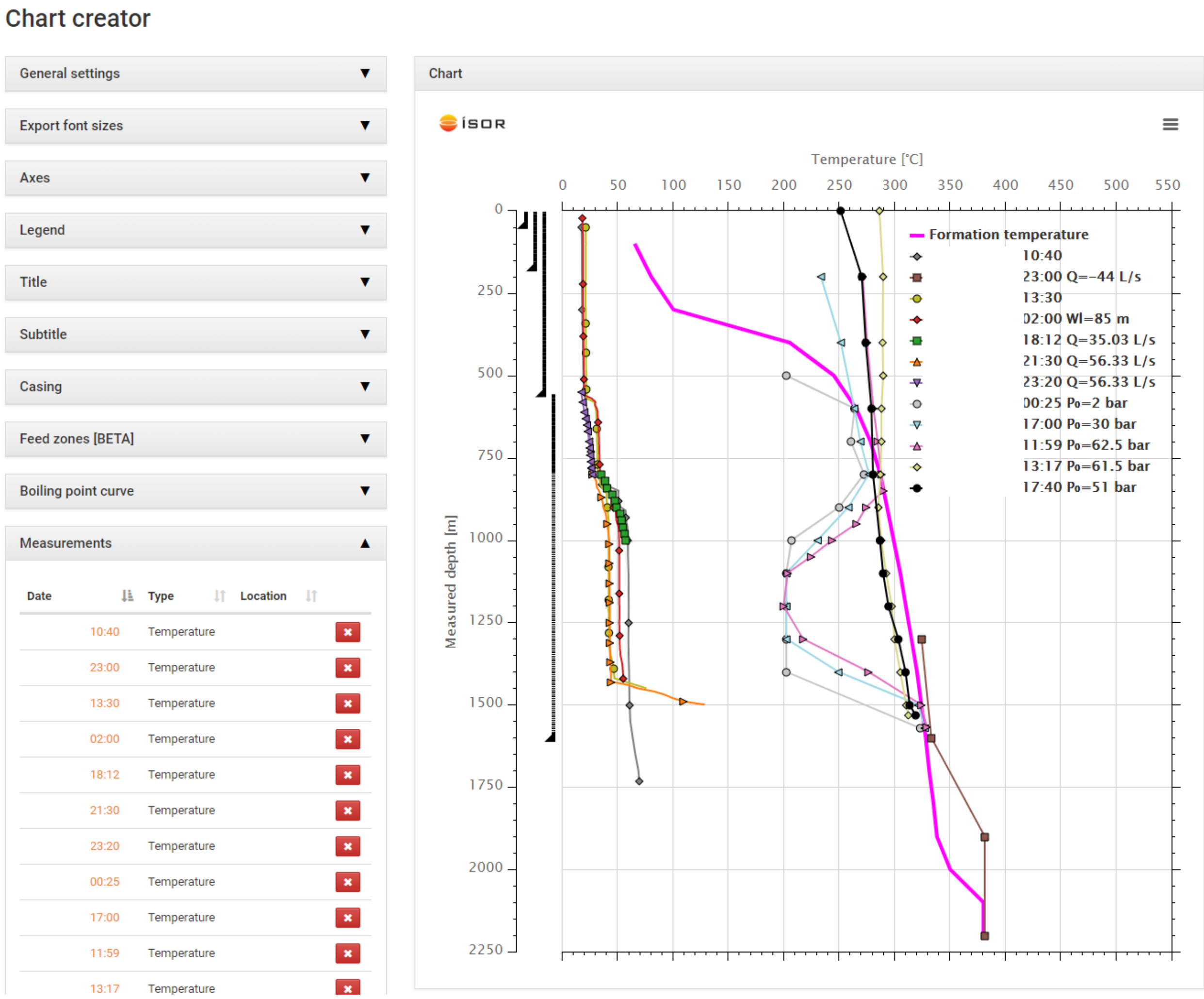


Figure 5. Selected temperature logs and formation temperature based on them.

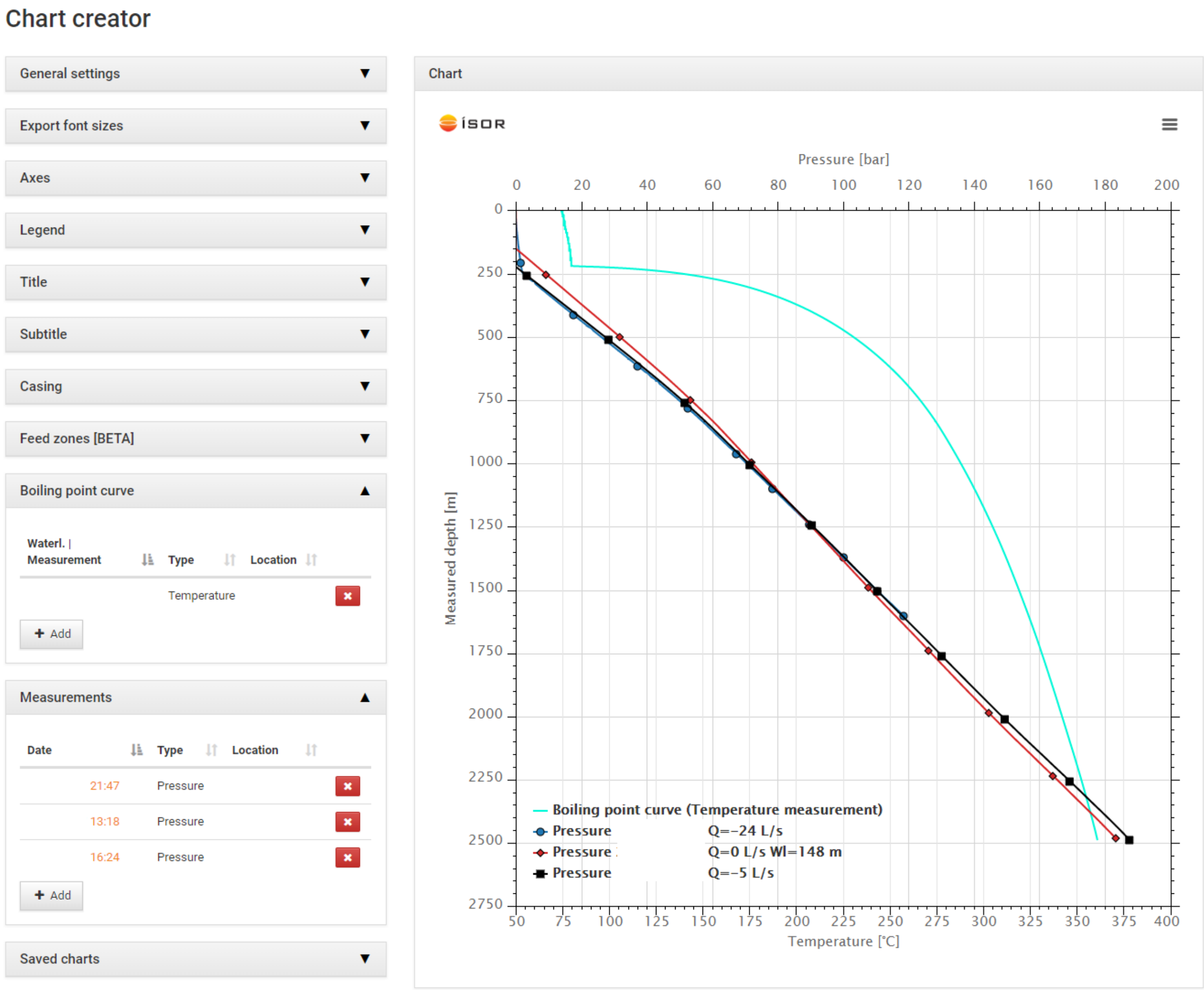


Figure 6. Pressure during heat-up of the well and corresponding boiling point curve.

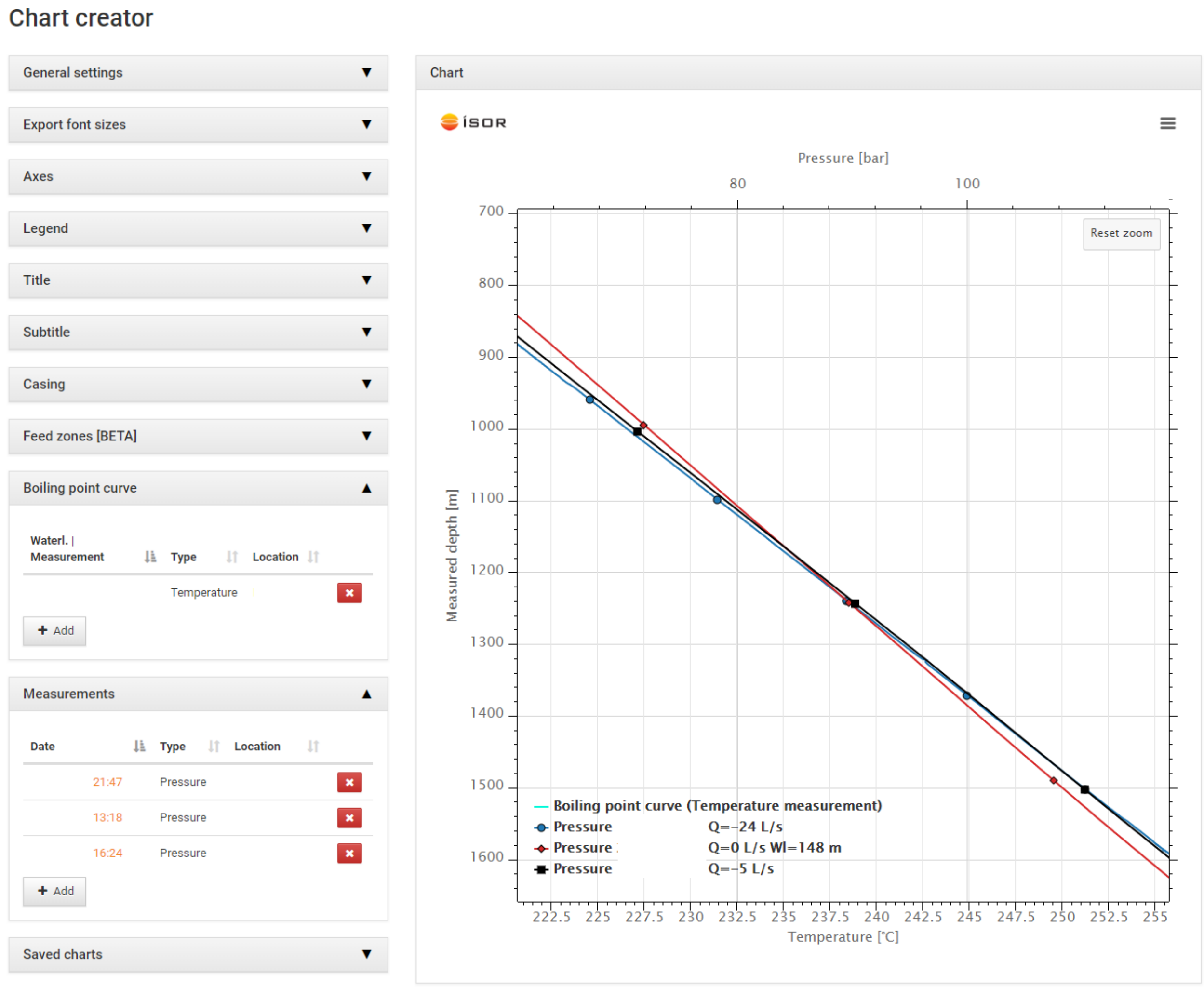


Figure 7. Finding the pivot point.

3. EXAMPLES OF MULTIDATA ANALYSIS USING VINNSLA

3.1 Estimating the location of feed zone using temperature and spinner logs

An example of where comparing different kinds of logs gives greater confidence of interpretation is the feed zone interpretation obtained through the joint comparison of spinner and temperature logs available at the end of drilling. An example of this is shown in Figure 8, where the feed zones are indicated by blue bands. A visual comparison of temperature and the spinner logs makes locating feed zones in the well a simple task. A change in the gradient of the temperature logs indicates a change in outflow as do the breaks in the spinner logs. The two datasets are complementary, some feed zones are visible in both the spinner and temperature logs while others are only visible in one log type. Once the depth of the feed zones has been estimated they are stored in the database. When evaluating data from the well at a later stage the feed zones may be reviewed, and their location modified. The ease of access to the feed zone locations and any well logs through this visual interface allows for the feed zones to be continually re-evaluated and their locations updated as needed.

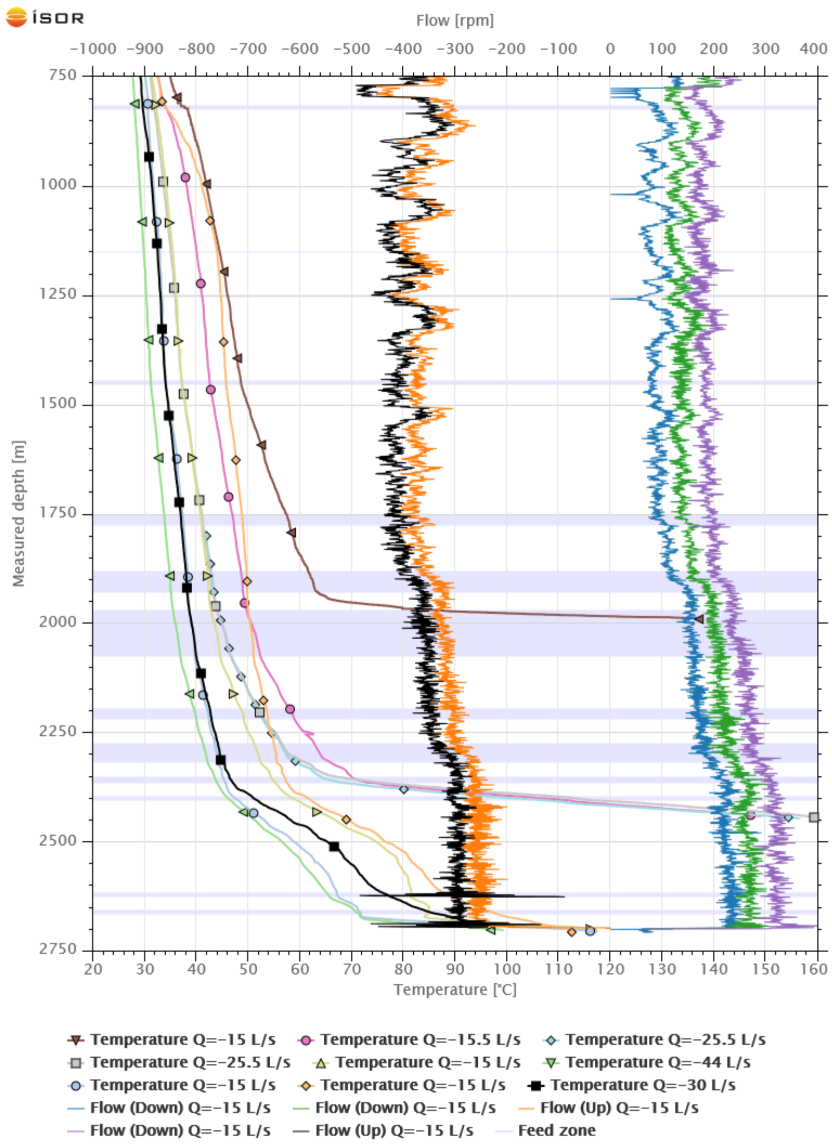


Figure 8. Temperature and spinner logs are complementary when estimating the location of feed zones in a well. Here the feed zones are blue horizontal bands.

3.2 Monitoring Logs: Visualizing the Evolution of Temperature and Pressure at key depths in the Reservoir

Geothermal systems are regularly monitored with temperature and pressure logs. Comparing new logs to logs taken in previous years gives good insight into any changes taking place in the system. Plotting timelines of temperature and pressure at key depths in the reservoir offers added insight and may highlight changes that are difficult to detect in downhole logs. An example of this would be plotting a timeline of temperature and pressure at the depth of a steam zone as well as at the depth of the liquid reservoir below the steam zone, see Figure 9.

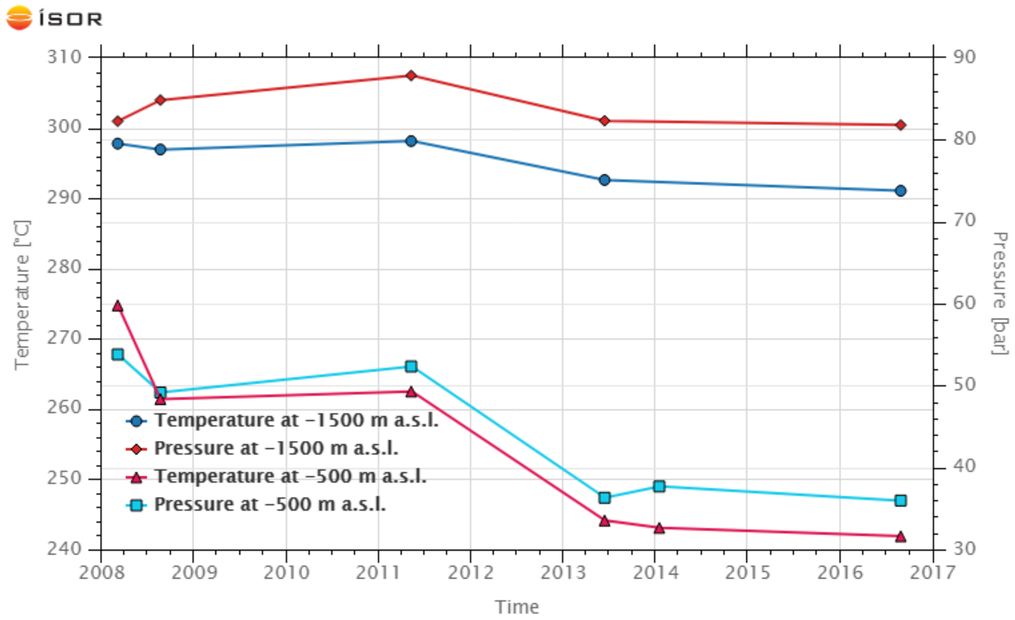


Figure 9. The temperature and pressure timelines at two different depths in a reservoir: One depth coincides with the reservoir steam zone and the other with the liquid part of the reservoir below the steam zone.

3.2 Estimating formation temperature curve

The VINNSLA-system can be used to estimate the formation temperature close to a well, using a package called BERGHITI. The package works by constructing a formation curve from different sources, e.g. well logs or boiling point curves. It is possible to select points from different logs taken during drilling, after injection or production, during injection or production or at a static condition. Formation curves often follow the logging values closely, e.g. at deep well depths. For closely spaced wells a user can use formation temperature from neighboring wells as an estimate. After choosing the points or segments for the formation curve, the package can interpolate between the points, making an equally spaced continuous curve. Figure 10 shows the estimated formation temperature in a well (LL-03) along with a comparison of the formation temperature in neighboring wells (Tulinius et al. (2019)). In this specific case, the top part of the formation curve has been adjusted so that all neighboring wells show a similar trend.

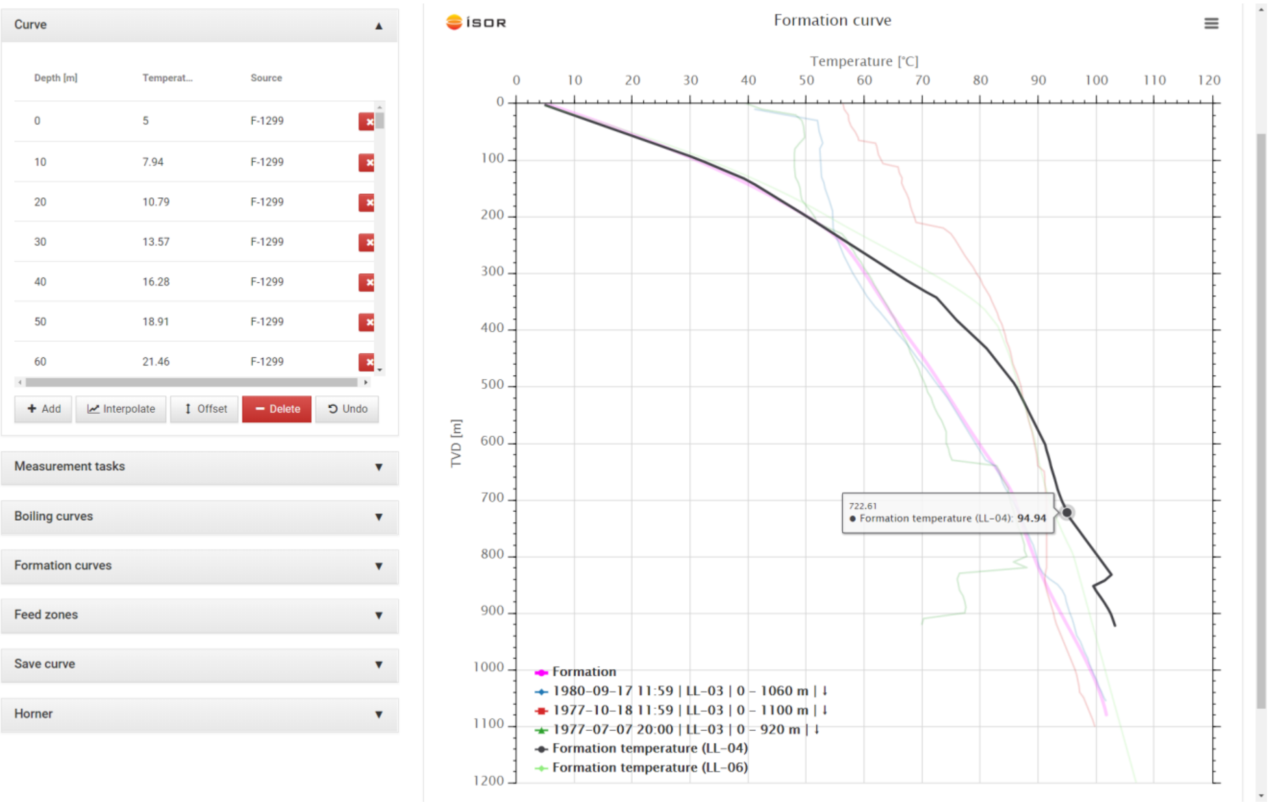


Figure 10. Points chosen from the temperature logs and interpolated between the points. Formation temperature from neighboring wells are used for comparison.

For high enthalpy wells part of the formation temperature (and pressure) often follows the boiling point curve with depth. Figure 11 shows a well where curve follows the boiling point curve down to about a 1000 m. This boiling curve was constructed by specifying the water level of the well. It is also possible to construct a boiling curve by using a well log. Below a 1000 m it is either possible to use the last temperature log taken before the well starts flowing or to use the Horner method to estimate the formation temperature at specific depths, and then to interpolate to create a smooth continuous curve.

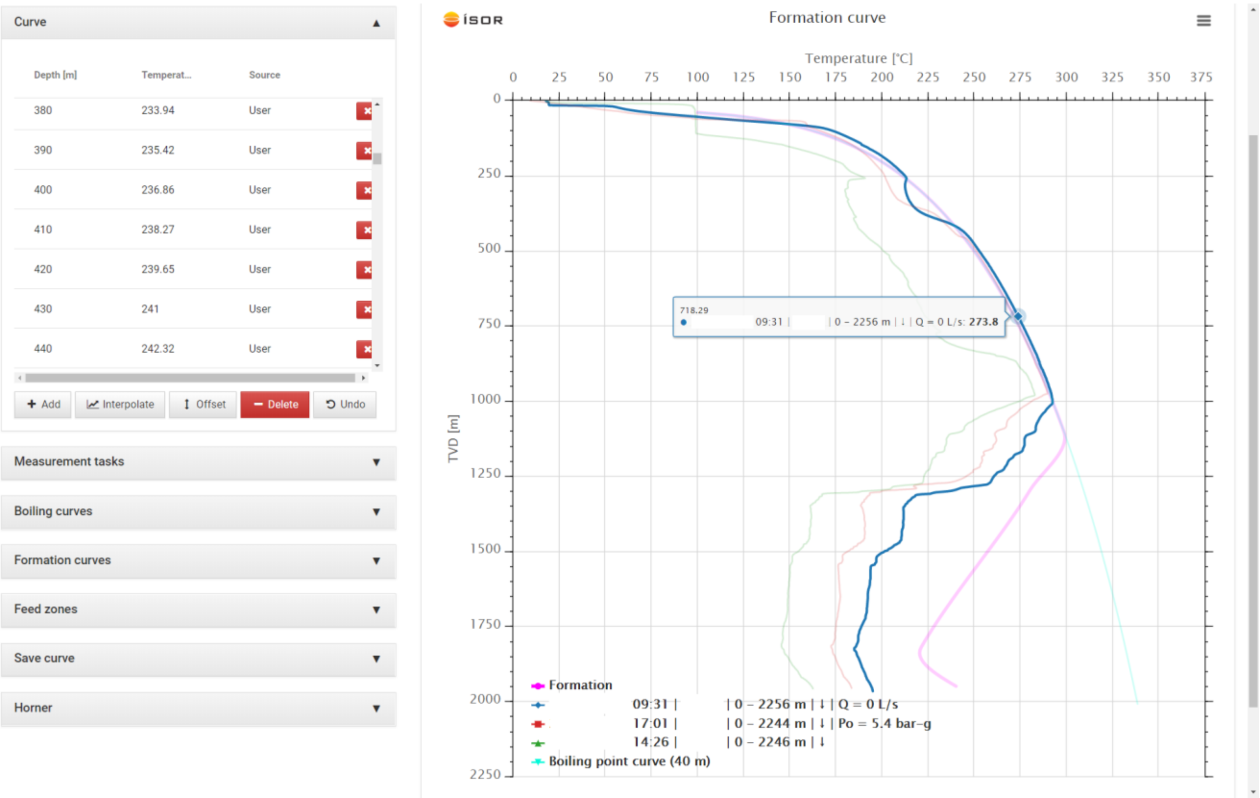


Figure 11. Estimating formation temperature where part of the curve follows the boiling point curve with depth.

Once a formation temperature curve has been estimated it is stored in the database. This formation curve can then be compared, later, to new logs in the well (and in neighboring wells). This allows users to monitor the evolution of the reservoir temperature close to the well, as the system is utilized.

4. CONCLUSION

The VINNSLA-system allows users to leverage the large quantity of data stored and organized at ÍSOR to perform a variety of detailed analyses on wells and geothermal systems. Having a centralized system means that new data is quickly disseminated to end users, which in turn can use different packages to quickly begin analytical work for a chosen location (i.e. wells). The ability to use different types of data from different sources means that a user can get a more complete overview of the data for a certain location or geothermal system. This in turns helps when assessing geothermal utilization of a system, saves time and minimizes errors.

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