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Status of the development of the numerical model of the Krafla geothermal system - May 1998

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STATUS OF THE DEVELOPMENT OF THE NUMERICAL MODEL OF THE KRAFLA GEOTHERMAL SYSTEM - MAY 1998

Introduction

At the request of Landsvirkjun, the development of a three-dimensional numerical model of the Krafla geothermal system was started in October, 1996. This model was needed because of the planned expansion of the electrical power generation from 30 MWe to 60 MWe, starting in the fall, 1997. The first phase of the development of the model was completed in June, 1997 and concentrated on the generating capacity of the Suðurhliðar wellfield, because of planned drilling in this area later that summer. It was always known that the status of the model in June, 1997 was preliminary and that much more effort was needed in order to make the Krafla model a reliable reservoir management tool. Yo achieve this, a second and final phase of this project was started in April, 1998. The main tasks involved in this effort include:

(i) Corrections of known shortcomings in the model.
(ii) Calibration of the model to the production history and the natural (initial) state of the reservoir
(iii) Performance predictions for various assumptions regarding future utilization

This brief write-up provides a summary of the progress made in the development of the Krafla model during these last two months, and also describes plans to complete the model in the fall, 1998.

Approach

A reliable reservoir model of a geothermal reservoir must match all of the relevant data obtained from the resource. The most important data that the model must be able to reproduce include the pressure decline data from idle wells, flow rate and enthalpy data from producing wells and the initial three-dimensional distributions of fluid pressure, rock temperature and liquid and steam phases (natural state conditions). The 1997 Krafla model was used as the starting point, thereby retaining the work that was invested in the conceptual model, the numerical grid and the natural state simulations. The model was, however, simplified to the extent possible by eliminating some of the somewhat artificial sources of water, steam and heat. The remaining and essential sources (upflow zones) include those in Hveragil, Suðurhlíðar, Leirhnjúk and Leirhól. The geothermal area at Hvíthóll is assumed to be recharged mainly from Suðurhlíðum, as suggested by isotope data and other geochemical evidence.

The numerical simulations have proceeded with concurrent natural state and production history simulations, utilizing the same numerical model, which is always updated after each iteration. The production history was initially simplified to allow for one complete computer simulation for the entire period (1974 to 1998) in approximately one-hour, thus enabling several simulations to be performed each day. The 1997 Krafla model mostly concentrated on the natural state simulations, so that much work was needed to establish pressure decline rates that matched observations, and the general flow rate and enthalpy trends in all flowing boreholes. This approach has allowed for rapid progress in matching the essential and important features of both the natural state and exploitation aspects of the Krafla system.

Natural State Simulations

Several improvements have been made in the natural state simulations and the present model for most wells shows reasonably good agreement with observed initial pressure, temperature and phase conditions. Globally speaking, the most improvements have been achieved in obtaining cooler conditions (about 200C) in the upper reservoir í Leirbotnum, better temperature and pressure profiles for all boreholes in Hvíthóll and some improvements for most Suðurhlíðar wells. Figures 1 and 2 show examples of measured and calculated temperature and pressure profiles for boreholes 7 and 21 in Leirbotnar and Hvíthóll, respectively. The figures show that good temperature conditions have been achieved in the upper reservoir in Leirbotnar and that the reversal in temperature is obtained by the model in Hvíthóll. Some improvements are still needed in reducing pressures deep in the Leirbotnar system. Figure 3 shows the observed and calculated temperature and pressure profiles for well 16 in Suðurhlíðar. The calculated temperatures are in reasonable agreement with the observed data in the upper part of the borehole, but the observed reversal deeper is not yet reproduced by the Krafla model. Also, there is improvement needed in increasing pressures by about 5 bars in the deeper parts of this well. Other wells located in Suðurhlíðar show similar results as those shown for borehole 16. Figure 4 shows calculated distributions of temperature, pressure and vapor saturation for layer H, which is the deepest layer in the Krafla model, residing approximately at elevations between 1500 and 1800 m.b.s.l.

Production History Simulations

Much improvements have been achieved in matching the production history of the Krafla field. The 1997 model showed much too great pressure decline in most of the Krafla reservoir system. As the observed pressure decline from idle wells such as wells 6, 16, 18 and 22 is the most important reservoir data in terms of the reliability of future predictions, much effort has been devoted to obtaining reasonable matches with these data. Figure 5 shows as an example the observed and calculated pressure declines for boreholes 6 and 18 in Leirbotnar and Suðurhlíðar, respectively. The figures show that the Krafla model shows very similar total pressure decline for both boreholes, although the detailed responses are somewhat different between the observed and calculated data. One cannot expect a detailed match between the observed and calculated values, because the Krafla model currently uses an approximate, simplified production history. Both the observed and calculated data show rapid recovery in pressure in borehole 6 and very little recovery in well 18. Similar match has been obtained for well 22 in Hvíthólar.
Work has also been devoted to the matching of the flow rate and enthalpy transients in producing wells. Figure 6 shows as an example the pressure, enthalpy, temperature and steam saturation for well 15 in Leirbotnar. In this figure calculated pressures and temperatures are given by solid lines, calculated enthalpy and steam saturations by broken lines, measured pressures and temperatures by squares, measured enthalpies by small dots. Figure 6 shows that the measured enthalpy transients for this borehole are closely matched by the calculated enthalpies. For some of the other wells the matches are not as good, such as for well 21 in Hvítholar, the reason in this specific case being that the natural state

temperature for this borehole is some 20C too cold (see Figure 7). This example clearly illustrates the importance of the coupling between the natural state and production history simulations.

Conceptual Model Changes

Few but important changes in the conceptual model of the Krafla field have emerged from the recent model development activities. Figure 8 shows the current rock property distribution in layer H, the deepest layer of the Krafla model. For comparison and correlation between the color scheme and the rock unit names the reader is referred to the report about the 1997 model authored by Grímur Björnson et al. The main changes include the addition of an E-W barrier located south of well 6 and all the way to south of well 17 (see red color blocks) and the addition of two fracture zones extending from the Hveragil fracture towards Suðurhlíðar (see green colored blocks). The E-W barrier was found to be necessary to match the pressure decline and the pressure recovery of well 6. This barrier limits the hydrological connection between well 6 and Hvíthólar and reversly increases the connection between this well and other nearby wells in the upper Leirbotnar system such as wells 3, 9 and 28. The inferred E-W barrier agrees well with resistivity data and interpretations by Knútur Árnason et al (1996). The northern fracture zone extending from Hveragil around Víti and to the north of well 20 is needed to provide heat to this part of the reservoir from the upflow zone in Hveragil, also to provide fluids directly to well 20 that actually intersects this feature. The southern E-W fracture zone transfers fluids from the upflow zone in Suðurhlíðar south of well 14 to the Hveragil fracture and these fluids then primarily flow to the south to Hvíthóll. Many other smaller changes in geological and hydrological features have been made, but these do not require detailed description. Perhaps the most important rock parameter changes required in the model were those outside the main reservoir areas, as these control the long term performance of the system. The pressure decline data in idle wells required a significant increase in the permeabilities of these outside areas in order to limit the calculated pressure decline. The outside permeabilities are now on the order of some 5 md, but were before about 1 md. This change should result in much better performance of the Krafla system from that calculated and predicted in the 1997 Krafla model report.

Plans To Completion

Although most of the global behavior of the Krafla wells is well represented in the current Krafla model, there are still many computer runs required until all necessary fine-tuning has been accomplished. It is expected that concurrent natural state and production history simulations will be needed throughout June, and at that time all of the Krafla data have been matched to the degree necessary and desired. All of the known shortcomingss in the 1997 model have been corrected already. Performance prediction simulations will be carried out in July and August, and these will include reservoir performance predictions for the next 30 years for the current electrical power production of 60 MWe. In addition, calculations will be made for highrer total power production (120 Mwe) as well as for cases specified by Landsvirkjun. Some cases of reinjection into the reservoir will also be studied.

Summary

The phase 2 of the development of a three-dimensional model for the Krafla geothermal system has progressed well over the last two months. The model is built on the 1997 Krafla model, but has been refined, especially in regard to how it reproduces the natural state and production history data from Krafla wells. Important changes in the conceptual model of the field have been found necessary to match the data, including significant increases in the permeability outside the main reservoir system and a E-W barrier south of well 6. These changes alone will have large impact on future performance of the field, and could result in much improved performance to what was predicted with the 1997 model.

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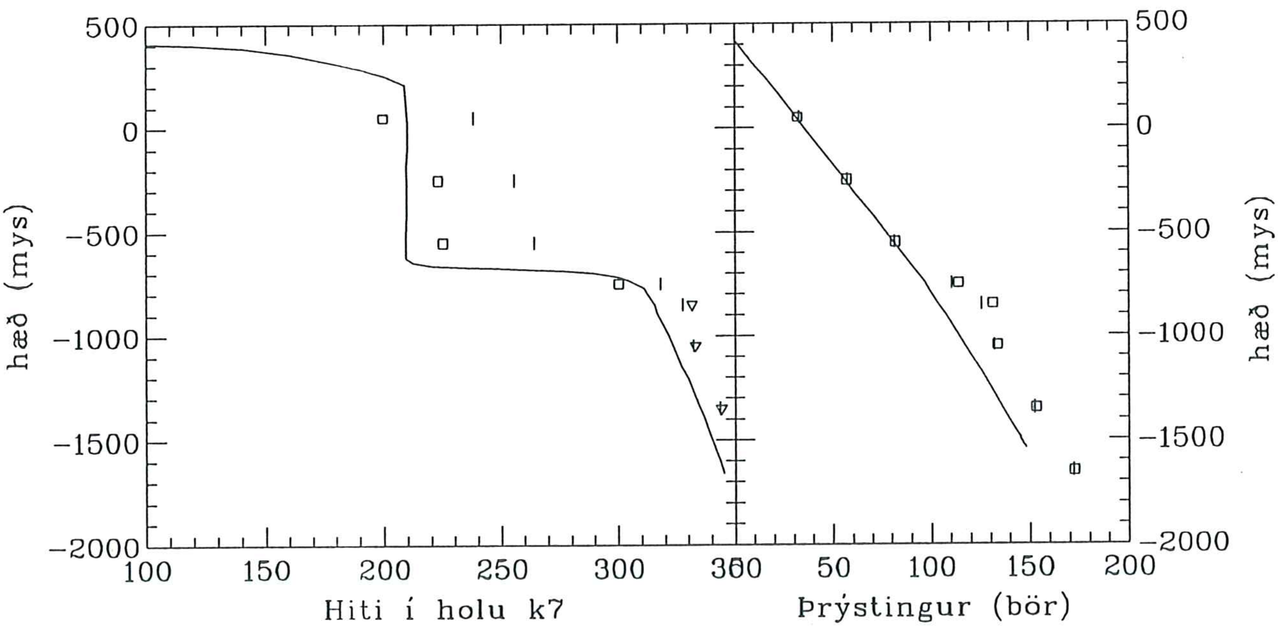


Figure 1: Measured and calculated temperature and pressure profiles in well 7.
The measured data are shown by solid lines.

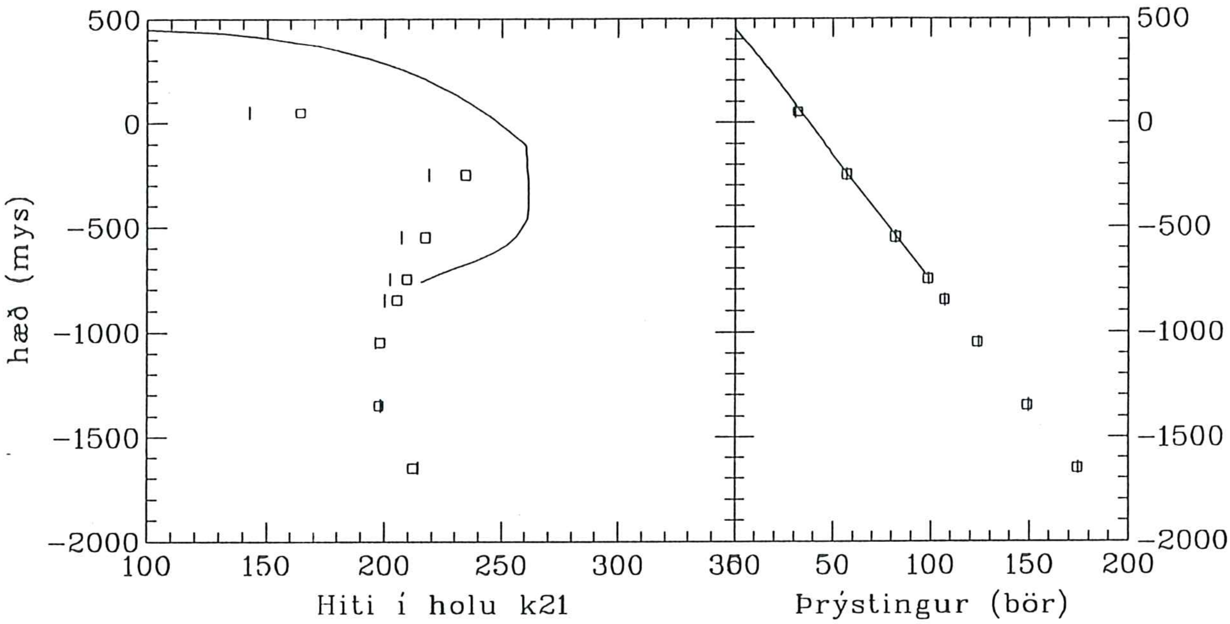


Figure 2: Measured and calculated temperature and pressure profiles in well 21.
The measured data are shown by solid lines.

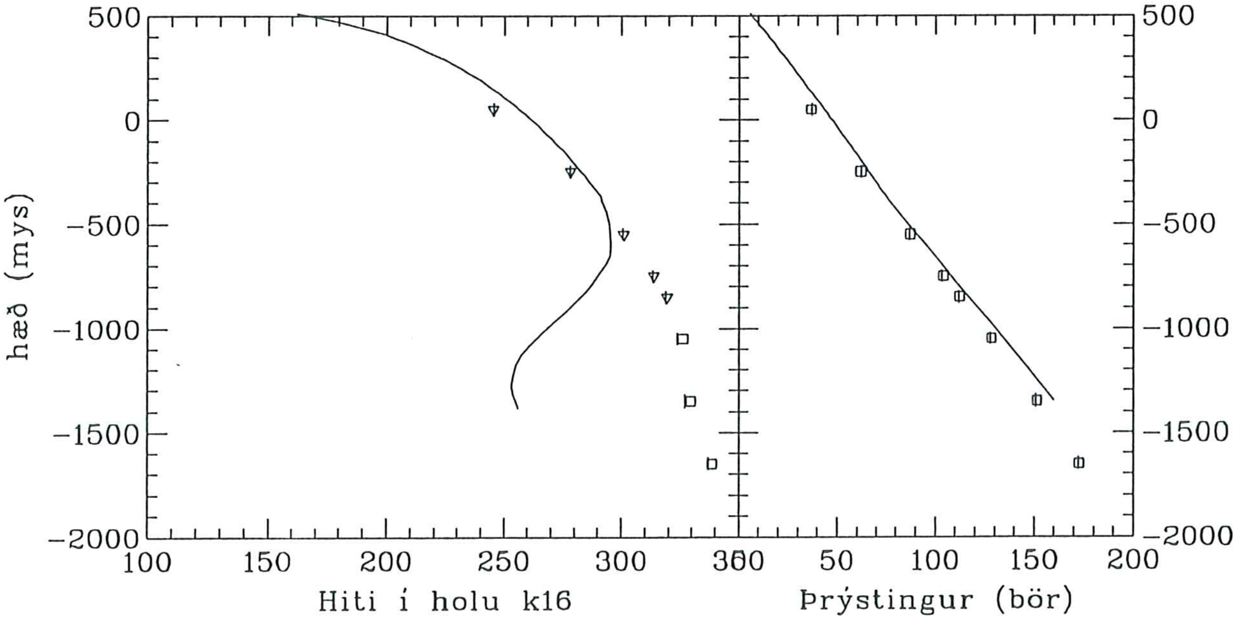
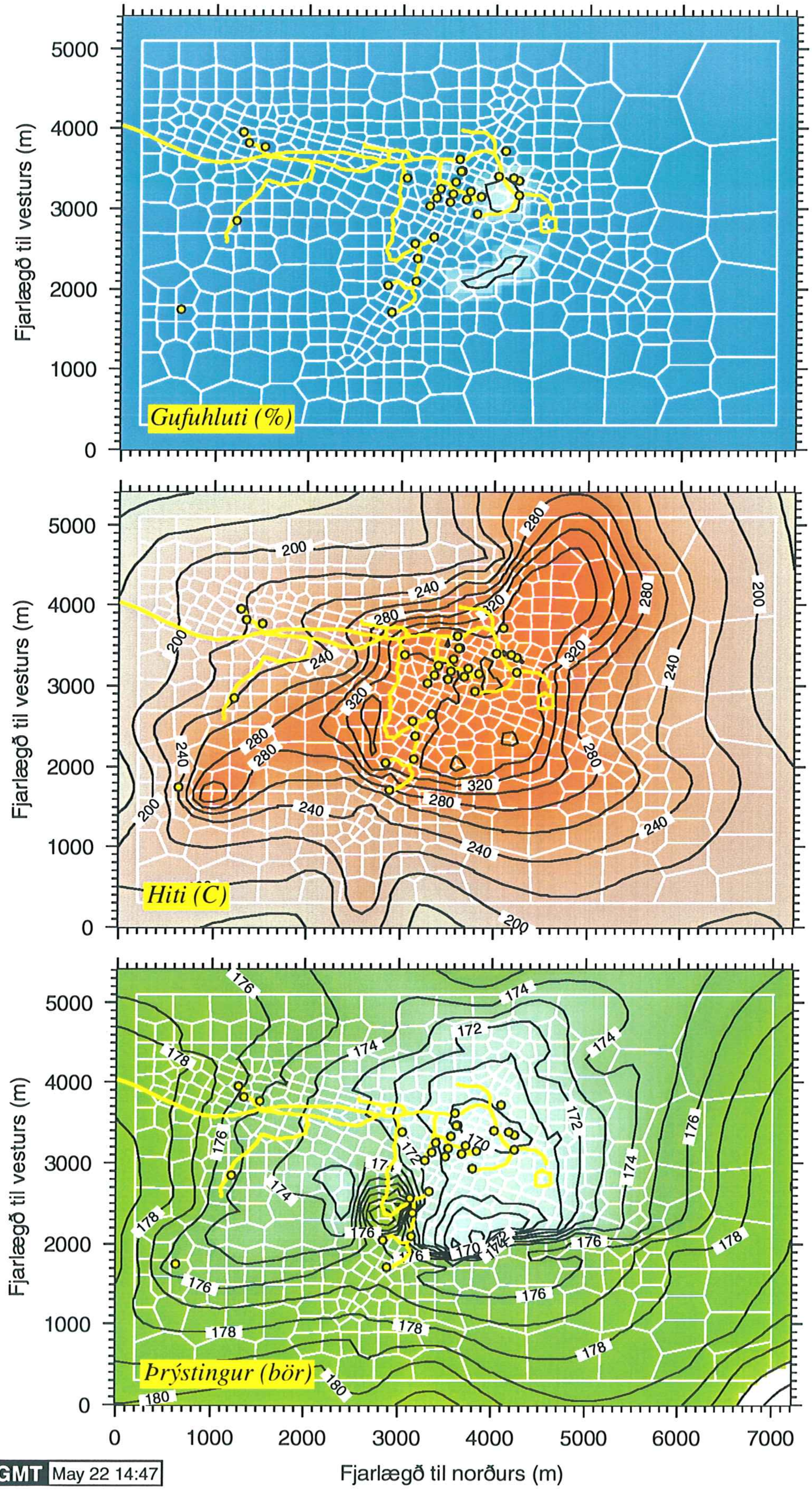


Figure 3: Measured and calculated temperature and pressure profiles in well 16.
The measured data are shown by solid lines.



Mynd B–8: Gufuhluti, hiti og þrýstingur í lagi H

Fig. 4

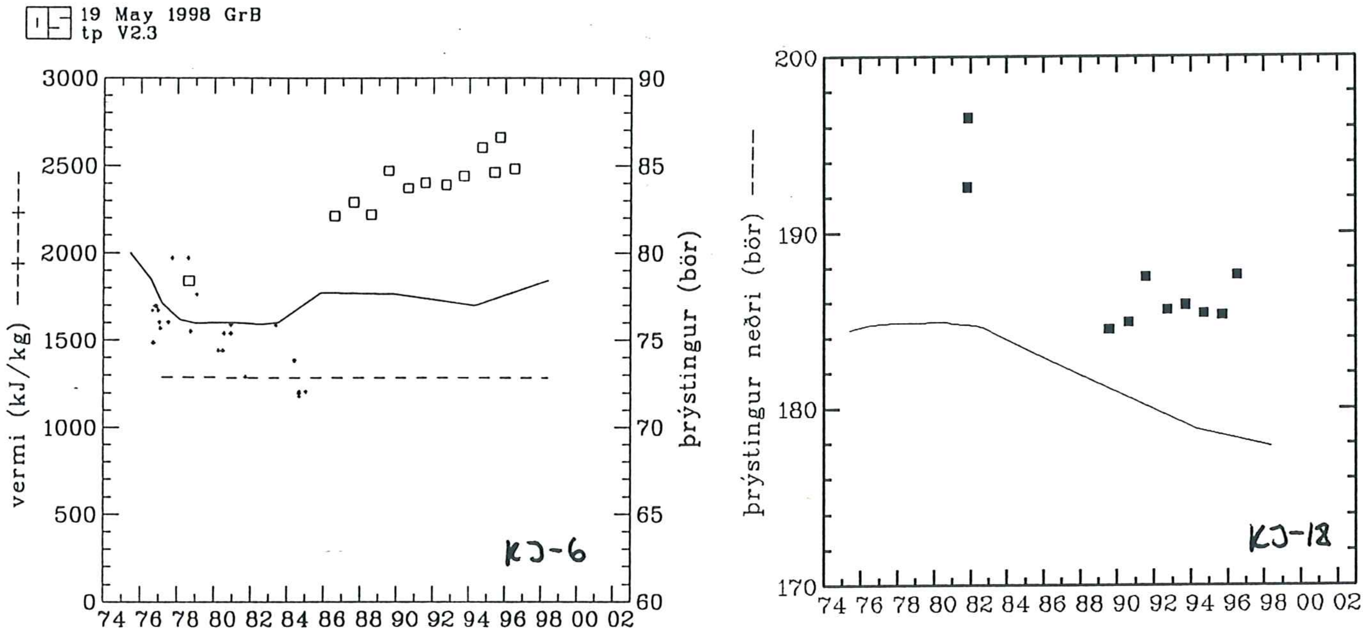


Figure 5: Calculated and observed pressure decline in wells 6 and 18 in Krafla.

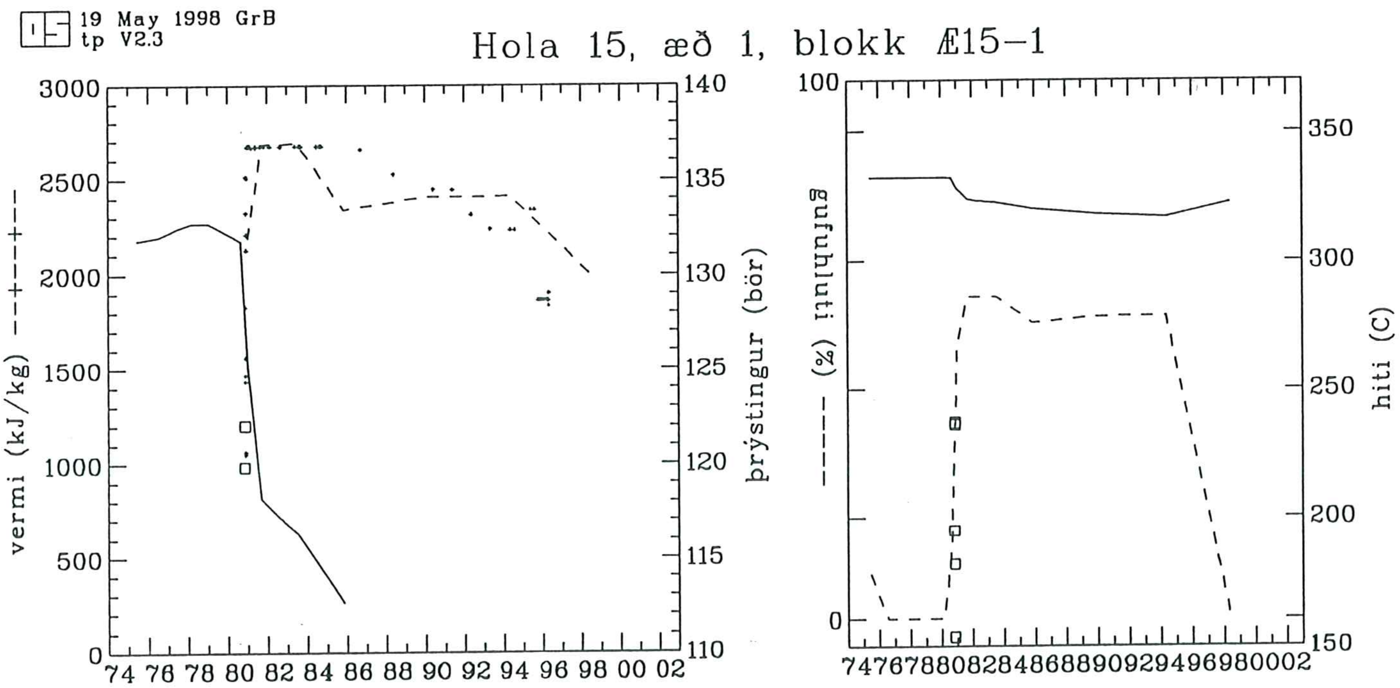


Figure 6: Calculated and observed pressure, enthalpy, temperature and steam saturation for well 15 in Leirbotnar.

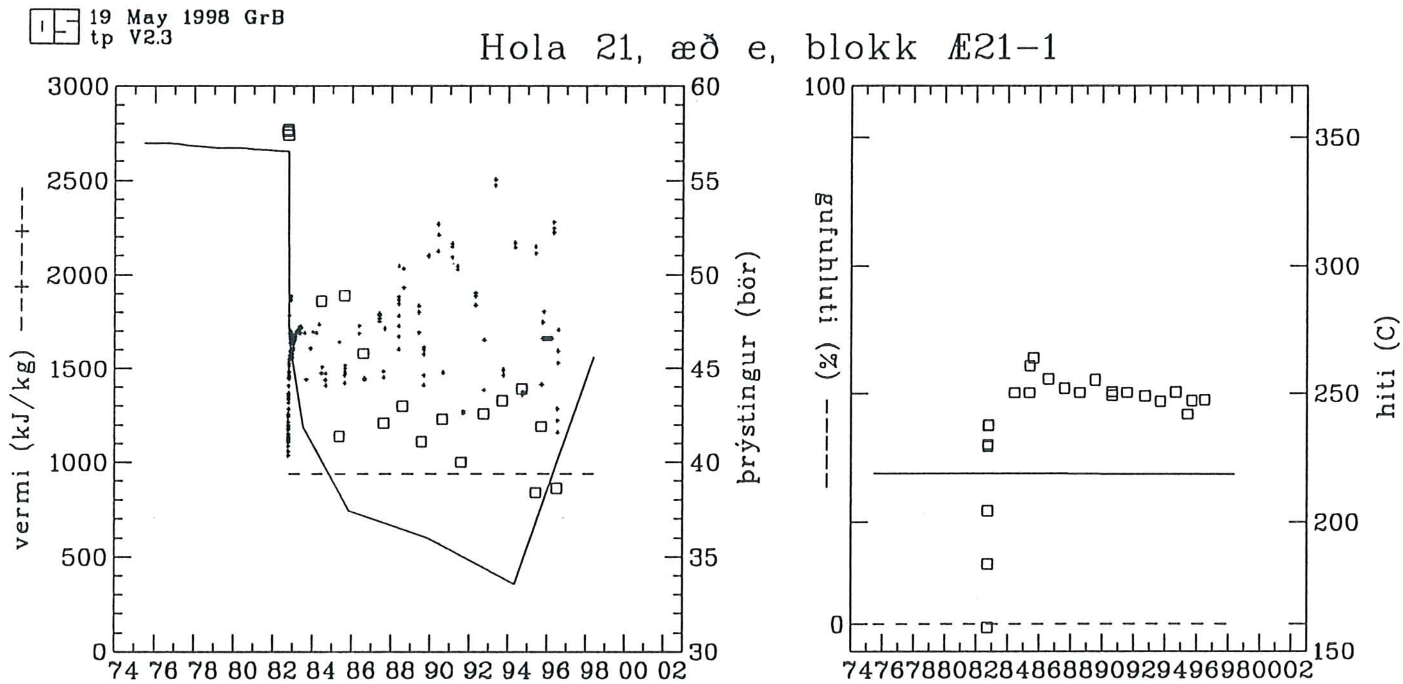


Figure 7: Calculated and observed pressure, enthalpy, temperature and steam saturation for well 21 at Hvíthólar.

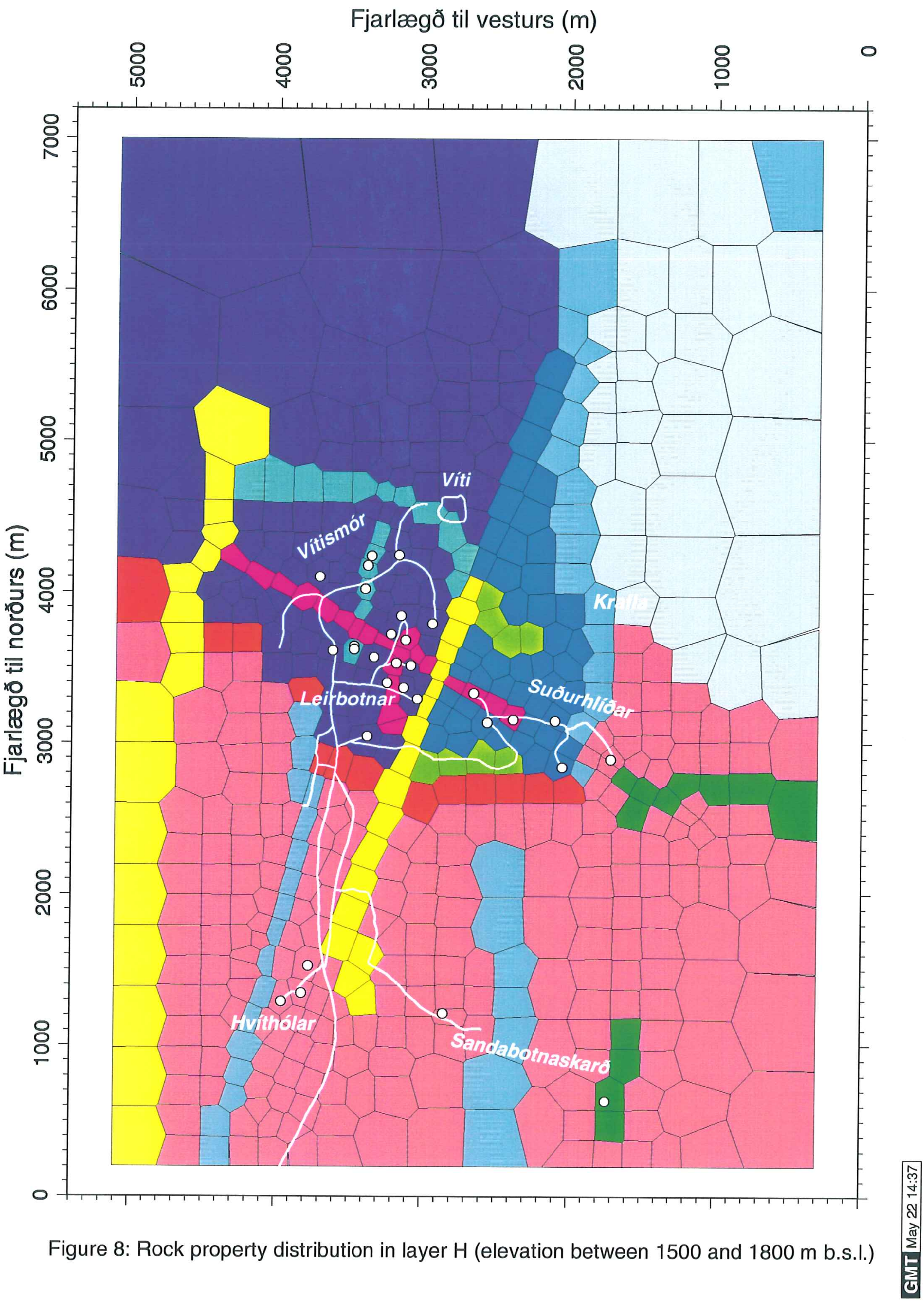


Figure 8: Rock property distribution in layer H (elevation between 1500 and 1800 m b.s.l.)