Thermal evolution of hydrothermal systems from a geologic perspective using Tough2, Los Azufres, Mich., Mexico

Gerardo García-Estrada
GPG, Comision Federal de Electricidad of Mexico
Alejandro Volta 655 Col. Electricista, Morelia 58290, Mexico

Abstract

In this paper we comment the use and limitations of Tough2 (Pruess, 1991) to model the thermal evolution of a high enthalpy geothermal zone from a geologic perspective, and the way in which we are working to reach this aim. The project, still in progress, has as one of its objectives to adapt Tough2 to model temperatures measured in exploratory gradient wells, in the same way that modelling is applied in geophysics, as a tool to establish boundaries for the geometry and properties of a hydrothermal system under study.

We use the expression 'from a geologic perspective' to mean the evolution of a hydrothermal system, and the associated volcanic heat source, in geologic time, from its emplacement to its complete cooling. As in gravity studies, in geophysical thermal interpretation we use the concept of regional-residual separation. The regional signal as the effect produced by predictable phenomena, and the residual one, associated with local unpredictable anomalies of heat and mass flow.

Tough2 is used to calculate the regional signal based on geological and geophysical data. If it is modeled as the steady state of the zone based only on the regional heat flow, the residual, calculated as the difference between measured and predicted data, corresponds to the anomalous effect produced by the magmatic heat source, that was not considered in the calculus. On the other hand, if we include parameters of the magmatic body for the calculus of regional, the residual signal corresponds to the effects of anomalies caused by the presence of faults not included explicitly.

Introduction

The Comision Federal de Electricidad of Mexico (CFE) has initiated exploratory drilling in medium to small size geothermal projects under geological environments quite different to that of the well known geothermal zones. Los Azufres Geothermal project, the most important producing field in the Mexican Neovolcanic Belt, is being used as a learning site, in which convective modelling, using PC version of Tough2 (Antunez et al., 1994) with module EOS1, is conducted in order to develop geological and geophysical criteria for the study and interpretation of data in poorly known areas.

A first stage of this project, consisting of geological an geophysical data interpretation, to have an idea of the heat source location, and a research to analyze the utility of thermal data measured in big diameter well during drilling stops, have been concluded. At present, the hydrothermal evolution modelling is currently conducted.

Conventional thermal geophysics modelling is limited to the use of conductive heat transfer programs. The reservoir is represented by rocks of high thermal conductivities, ten to twenty times a normal value. This procedure permits to fit calculated to measured data, but at the same time conducts to conclusions difficult to accept if convective phenomena are not included as an integral part of the thermal modelling. The need to include convective modelling makes advisable the use of Tough2 program for geophysical studies, profiting of its open architecture that permits the necessary modification to use it in this non conventional way.

The thermal modelling of Los Azufres from an Earth Sciences perspective is a problem that can be divided in four different sub-problems, in the same way that any other geophysical project: data compilation, data reduction, processing and interpretation.

The use of Tough2 as a tool to estimate the 'normal' predictable temperatures can be included as part of data processing. Difficulties associated to compilation, reduction and interpretation are not discussed here, and attention is centered on the activities conducted to adapt Tough2 to temperatures processing.

Procedure

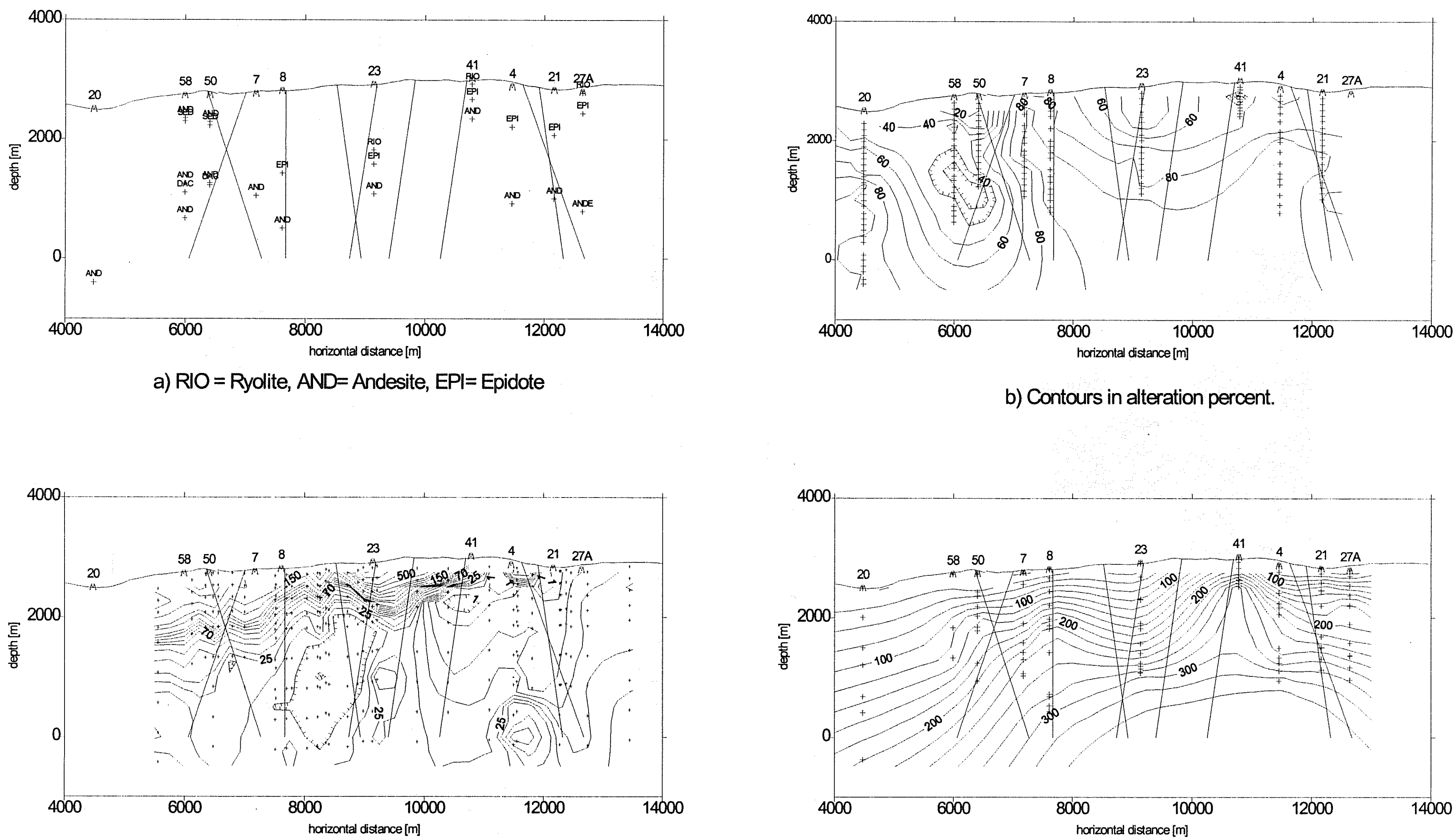
Some times in thermal studies, it is necessary to proceed in a trial and error basis to test the correctness of different analyzed hypothesis, in the same way as in gravity modelling. To make an efficient use of Thoug2, internal subroutines were included to permit graphic display of input and output data: geometry, physical properties, initial and temporal thermodynamic results. They all are used directly as input for commercial graphic and contouring software.

Graphic interface subroutines are completely compatible with Tough2 original structure, input and output data transfer are conducted trough a few additional common blocks. In spite these subroutines are not real time displays they have been very useful, and necessary for the use of Tough2 in this project.

For the study of the heat source in a high enthalpy geothermal system it is convenient to have the capability to model temperatures up to the typical values of magma flows, from 600 to 1200 °C under the assumption that can be representative of magmatic intrusive temperatures.

To reach this goal we included subroutines covering the thermodynamic regions numbered 3 and 4 by the International Formulation Committee, 1997. The implicit formulation are inverted using the Newton-Raphson method.

As preliminary results of this project, Figure 1 shows a profile with geological and geophysical data used to delineate the geometry of Los Azufres, based on recent studies (Garcia, 1995). Figure 2 shows the model's geometry based on Earth Sciences data. The steady state was produced with a fixed 20 °C superficial temperature and a heat flow of 100 mW/m^2 , fixed in the lower boundary (mean value of the heat flow province). Differences between calculated temperatures of Figure 2 and measured data of Figure 1 are the residual effect associated to the magmatic heat source and comprises all the secondary effects not considered explicitly in the calculus (Figure 3).



a) RIO = Ryolite, AND= Andesite, EPI= Epidote

b) Contours in alteration percent.

c) Contours in Ohm.m

d) Contours in °C

Figure 1.- Los Azufres, Mich. Well numbers are indicated in the upper part.
Straight lines indicate apparent dip of main faults.
a) Litologic contacts.
b) Hydrothermal alteration percent.
c) Apparent resistivity (DC soundings).
d) Drilling temperatures.

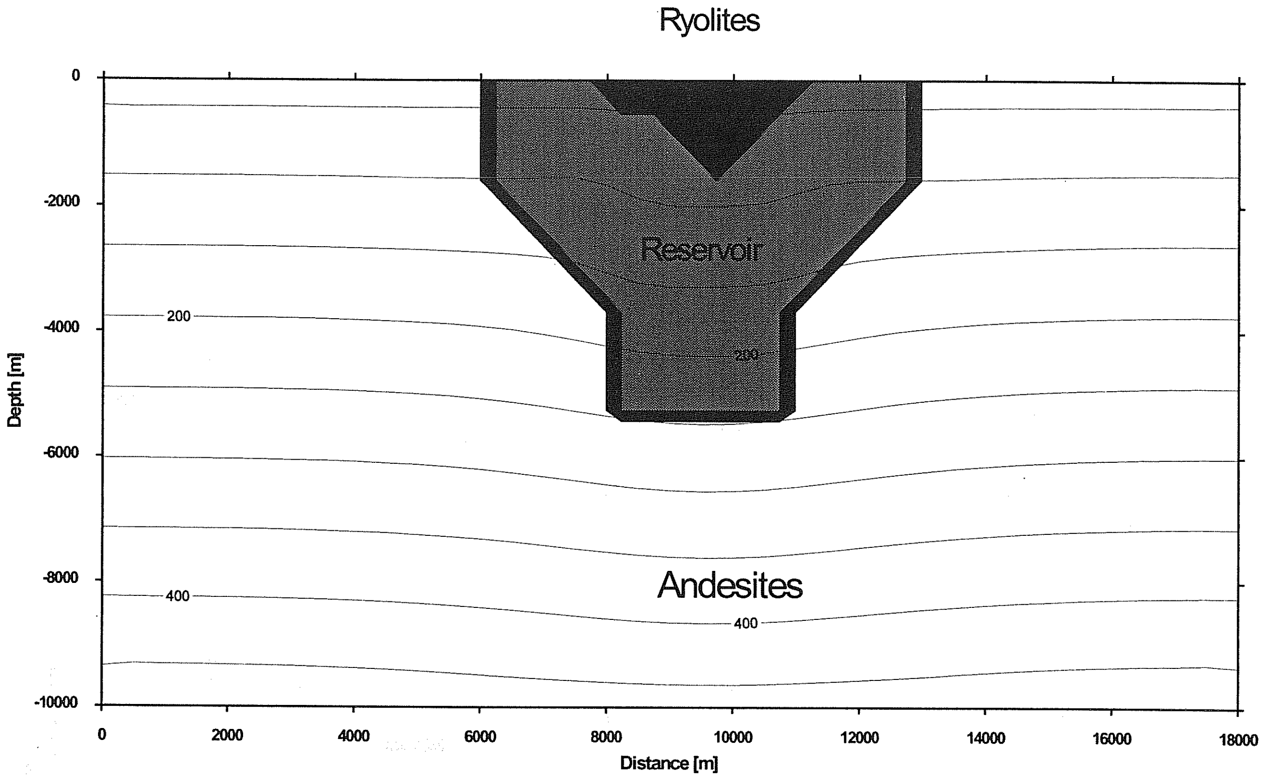


Figure 2.- Model geometry and calculated temperatures with a fixed top temperature of 20 °C and heat flow 100 mW/m2 on the bottom.

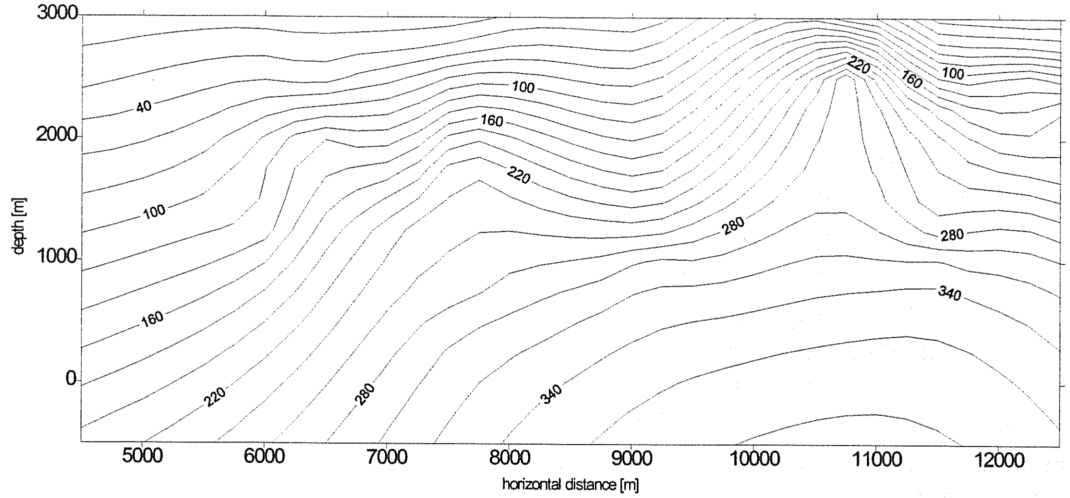
Our following objective is the inclusion of a cooling shallow intrusive for the calculus of the theoretical regional temperature, we attempted to simulate its instantaneous placing in the same way that in conductive modelling, but we have found that this procedure produces instabilities in Tough2 solvers. Future developments require to find a way to avoid this instabilities trough the appropriate use of Tough2 options or simulating the progressive ascent of the magmatic source.

Conclusions

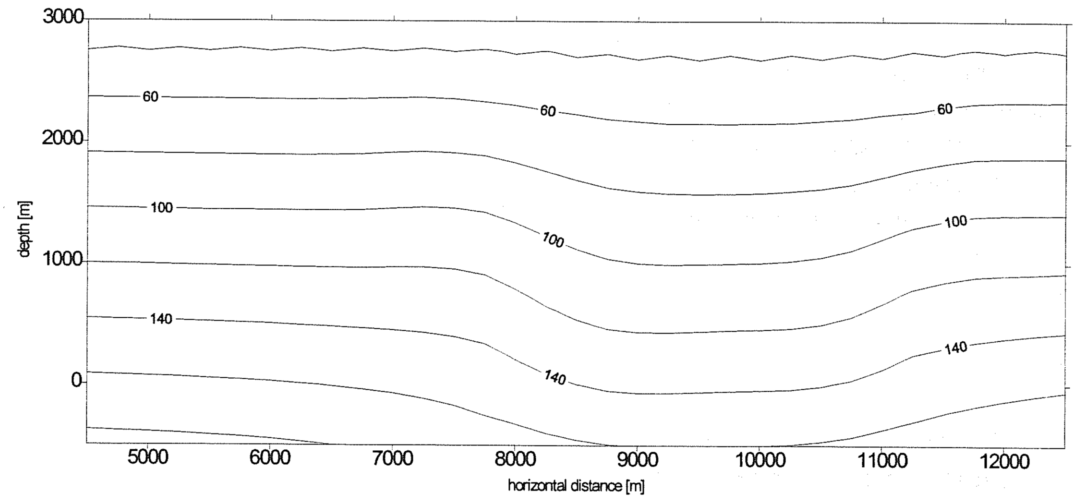
The use of Tough2 from an Earth Sciences perspective required the development of efficient graphic interfaces in order to make possible a trial and error procedure to adjust the geologic parameters and geometry to fit calculated and observed data using very simple geometries.

In order to simulate the convective cooling of the intrusive acting as the heat source of the geothermal field and to compare this temperatures with results of the purely conductive models, normally used to interpret temperatures in exploratory wells, we developed subroutines to cover a wider thermodynamic range, up to 1000 bar and 800 °C.

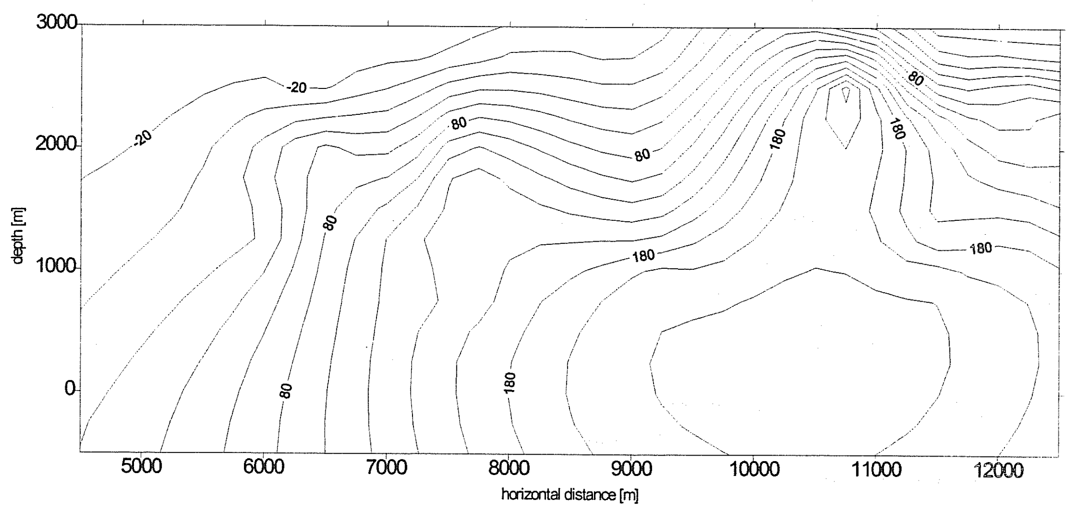
Thermal data of Los Azufres geothermal



Measured temperatures.



Regional temperatures (calculated with Tough2).



Residual temperatures (measured - calculated).

Figure 3.- Measured, regional and residual temperatures.
Contours in °C.

project are currently used to test these developments and at the same time to develop criteria to interpret temperatures measured in gradient and slim holes in less known exploration zones. The use of these data coming from big diameter wells required a detailed analysis to evaluate the utility of temperature data, measured during drilling stops of production bore holes, as representative of a pre-drilling thermal equilibrium stage.

At present, we work in the development of procedures to simulate the intrusive emplacement, in order to avoid convergence difficulties with the algorithms, caused by the big thermodynamic conditions differences between the intrusion an the host rocks, and problems associated to thermodynamic discontinuities of water properties.

References

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