Numerical Model of the Travale Geothermal Field (Italy) in the Framework of the I-GET European Project

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Numerical m odeling, TOUGH2, Travale, I-GET

ABSTRACT

In the framework of the I-GET European Project, the natural state and the production history of the Travale geothermal field have been simulated by means of the 3D numerical simulator TOUGH2.

This work was mainly aimed at investigating:

- the interactions between the geothermal field and the surrounding deep aquifers including their long distance pressure draw-down;
- the field sustainability.

The simulated area is about 200km^2 and is placed in southern Tuscany. The structural geological and geophysical analyses have been used as input data for this "regional scale" modeling.

To fulfill the work aims no constant pressure boundaries (i.e. mass sources) were introduced.

The thickness of the domain is 7000m, according to the location of a seismic reflection horizon which is believed to represent reservoir bottom. The reservoir top is made of impermeable rocks, which acts as cover of the geothermal system.

Natural state modeling has been based on the comparison between simulated and observed temperature and pressure data. The observed ones have been obtained by thermal and pressure profiles of Travale wells. During processing steps, rocks geophysical parameters (porosity and permeability) could be changed to optimize the simulated results.

The history of the industrial exploitation was then introduced and the relevant pressure distribution was compared with the actually recorded data.

Satisfactory results were achieved, and field production resulted sustainable for at least the next 50 years.

Introduction

ENEL Green Power participated in European Consortium to implement the I-GET project (Integrate Geophysical Exploration Technologies for deep fractured geothermal systems), financed by the European Union.

This project has been aimed at developing innovative methods to interpret geological and geophysical data for the identification of fractured zones in deep geothermal reservoirs. This new approach has been tested in four European geothermal systems with different geological and thermodynamic characteristics.

In the framework of this project the natural-state (before industrial exploitation) and production history of the Travale geothermal field have been simulated by using the numerical simulator TOUGH2, which is a tri-dimensional numerical simulator of non isothermal multicomponent flows.

Historical Field Exploration

The simulated area, which is part of the Travale geothermal field, covers about 200km^2 in the southern part of Tuscany (Figure 1). The geological and structural characteristics of the Travale geothermal field resulted from the tectonic evolution of southern Tuscany.

The exploitation of Travale geothermal field began in the early '50s (Figure 2). The wells tapped producing layers in various areas at different depths. For sake of simplicity, the field could be subdivided into four reservoirs according to structural and hydrological setting and to different fluid characteristics.

During the early '50s (Barelli et al., 1995) about 20 exploration wells were drilled to a depth of few hundred meters near the natural manifestations, in a water dominated system. Fluid production caused a decrease in reservoir pressure triggering the inflow of meteoric water. For this reason, all the shallow wells were soon watered out.

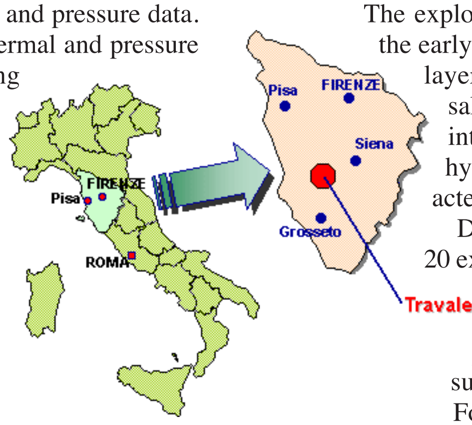

Figure 1. Travale field location.

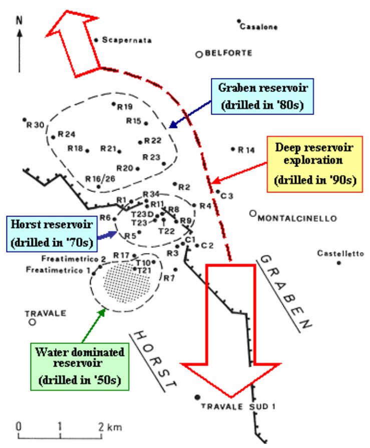

Figure 2. Travale exploration history.

Subsequently, in the '70s, the exploration was extended northward aiming at a deeper and hotter reservoir, named "Horst" (Figure 2).

This is a steam dominated system, met at a depth of 500-1000 m in carbonate formations with a pressure of 6MPa and a temperature of 280°C, and interconnected with the previous water dominated one.

Before exploitation, the steam reservoir was in hydraulic equilibrium with a pressure probably slightly higher than the hydrostatic one. Several surface natural manifestations were present, but the intense exploitation caused an inversion of the natural flow.

At the beginning of the '80s, the exploitation was northward extended to a deeper reservoir, named "Graben". This latter covers a larger area at a greater depth (1300-2000m) and had an initial pressure of about 6MPa with temperatures of 250°C-280°C. This reservoir experienced a continuous flow-rate decline without substantial changes in steam quality and gas content.

After 1992, few wells were drilled up to 4000m all over the field area, investigating a deeper reservoir hosted in the metamorphic basement, and hypothesized on the base of seismic reflecting horizons.

This reservoir is a superheated steam system with an initial pressure of 7MPa in vaporstatic equilibrium with all the previously discovered reservoirs, temperatures of about 300°C-350°C and gas content of 6%. A schematic representation of the Travale reservoirs is shown in Figure 3.

Domain and Simulation Grid of Numerical Modeling

The simulation grid is made of 8000 cells, subdivided into 20 vertical layers (Figure 4). The simulation area is 196km^2 and vertical thickness is nearly 7000m (from +800m a.s.l. to -6000m a.s.l.).

Each horizontal layer is formed by 20x20 cells with different sizes. A greater details is necessary in the inner simulation domain with a cell size of 0.5x0.5 km. In the bordering area, 2x2 km cell size has been adopted.

The cell thicknesses vary with depth; the deeper cells are 1000m thick, while the shallow ones are only 200-300m.

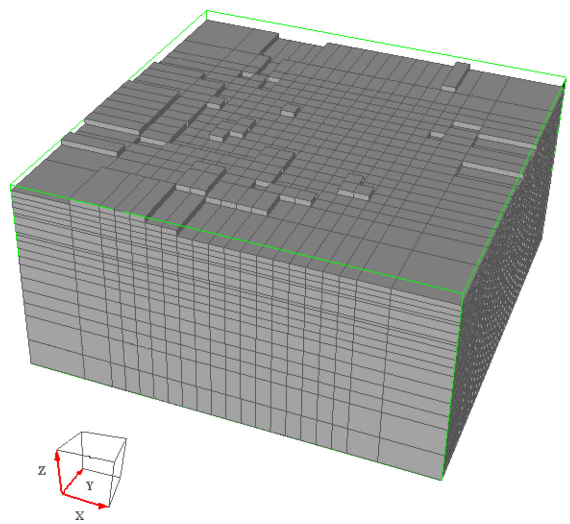

Figure 4. 3D simulation grid.

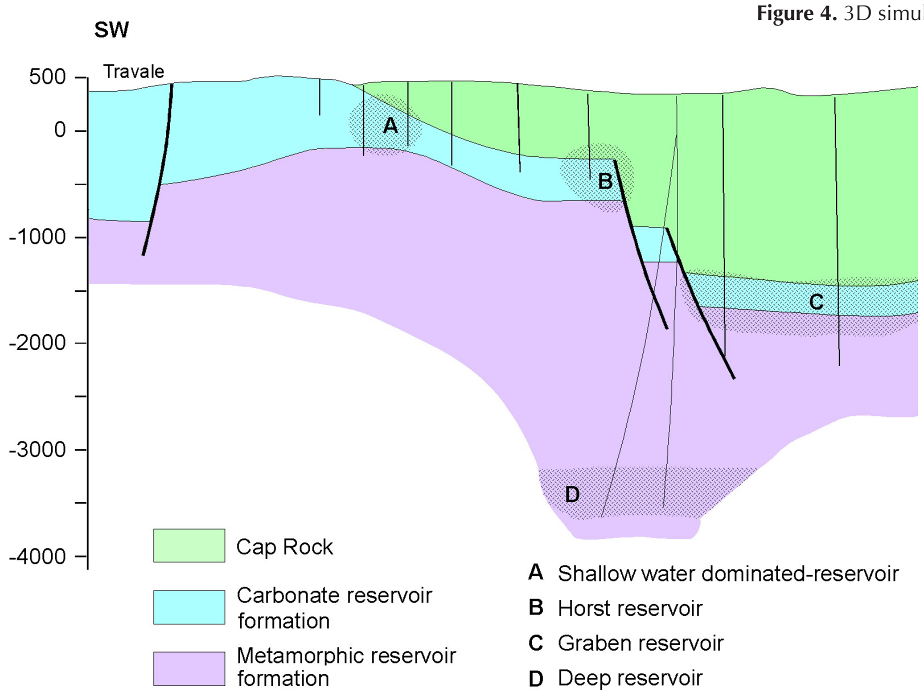

Figure 3. Geological section of Travale field.

The modeling has been performed by means of TOUGH2 numerical code, that was set using basic EOS ("equation of state") module. This last provides a description of pure water in its state phases (liquid, vapor and two-phase states). All water properties (density, specific enthalpy, viscosity and saturated vapor pressure) are supplied by the International Formulation Committee steam equation tables (1967).

Boundary Conditions

To demonstrate field sustainability using this numerical model, no-mass sources must be introduced as boundary conditions. Consequently, all the borders have been set as no-flow boundaries. The results of the natural state simulation have been used as cell initial conditions for production history simulation.

Boundary conditions have been imposed as fixed temperatures and pressures at top and

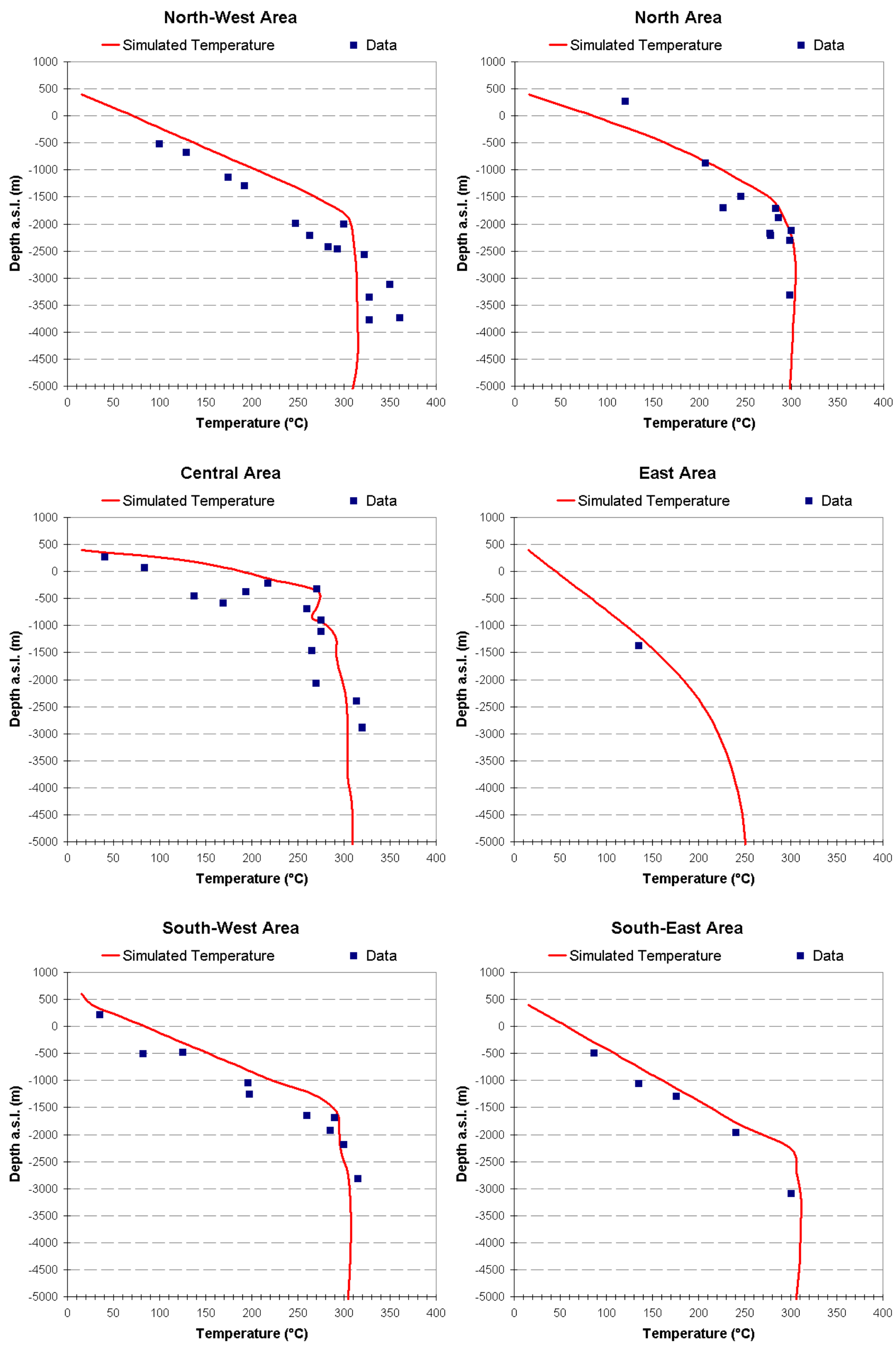

Figure 5. Simulated and observed temperature vertical profiles.

bottom of the simulation grid. In particular, a temperature of 15°C and atmospheric pressure were chosen for top cells. The only interactions between the geothermal reservoir and the external environment are the natural manifestations and a shallow aquifer where the cover is absent. Natural manifestations have been modeled as producing wells at constant pressure (atmospheric pressure), while the shallow aquifer occupied two cells with imposed constant pressure.

Temperatures varied between 250°C and 320°C for bottom cells, according to temperature distribution data, and pressure was considered constant at about 7MPa according to the deep reservoir pressure.

The lower limit of the model has been set at about -6000m a.s.l in correspondence with K seismic horizon (Fiordelisi et al., 2005). It has been considered impermeable, but allowed the natural heat flow to take place.

Geological Features of the Model

The cap rock is formed by impermeable layers of neogenic sediments and of flysh facies formations. It is characterized by a very low value of permeability.

The shallow reservoir is formed by carbonate rocks, while the deep one is formed by metamorphic rocks. Both these reservoirs have different values of permeability depending on depth. As already defined, the reservoir bottom is identified by the K-horizon.

Model Tuning and Natural State Results

Model tuning was based on comparison between simulated and actual distribution of temperatures and pressures in the natural state.

Simulated temperature, pressure and steam quality distributions have been obtained by modeling Travale natural state, while the actual data come from thermal and pressure well profiles.

During model tuning, rock parameters such as porosity and permeability were changed to optimize the simulation results. These three-dimensional distributions were used to simulate field production history and to evaluate the future system evolution and sustainability.

In particular, the matching between simulated and observed temperature and pressure horizontal distributions have been mapped at different depths, yielding satisfactory results. The comparison between simulated vertical temperature profiles and well data is shown in Figure 5.

Travale field has been subdivided into six zones defined on the basis of reservoir thermodynamic characteristics. For each zone, simulated and observed temperatures have been compared with satisfactory results.

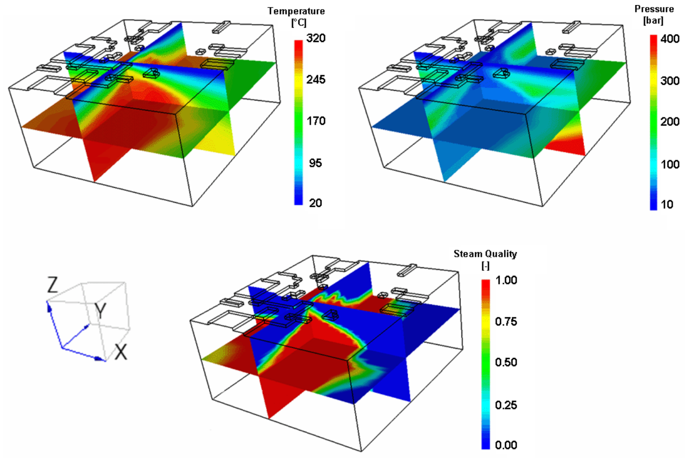

Figure 6. Temperature [°C], pressure [bar] e steam quality [-] three dimensional distribution for natural state.

Also temperature, pressure and steam quality 3D distributions have been displayed for natural state (Figure 6).

Production History Matching

The historical data of the industrial exploitation have been introduced and the simulation for about sixty years (1950-2008) of industrial exploitation has been performed.

The decrease with time of simulated pressure in many wells has been compared with data at different depths (Figure 7). To improve the match of pressure evolution with time, slight variations have been applied to rock parameters.

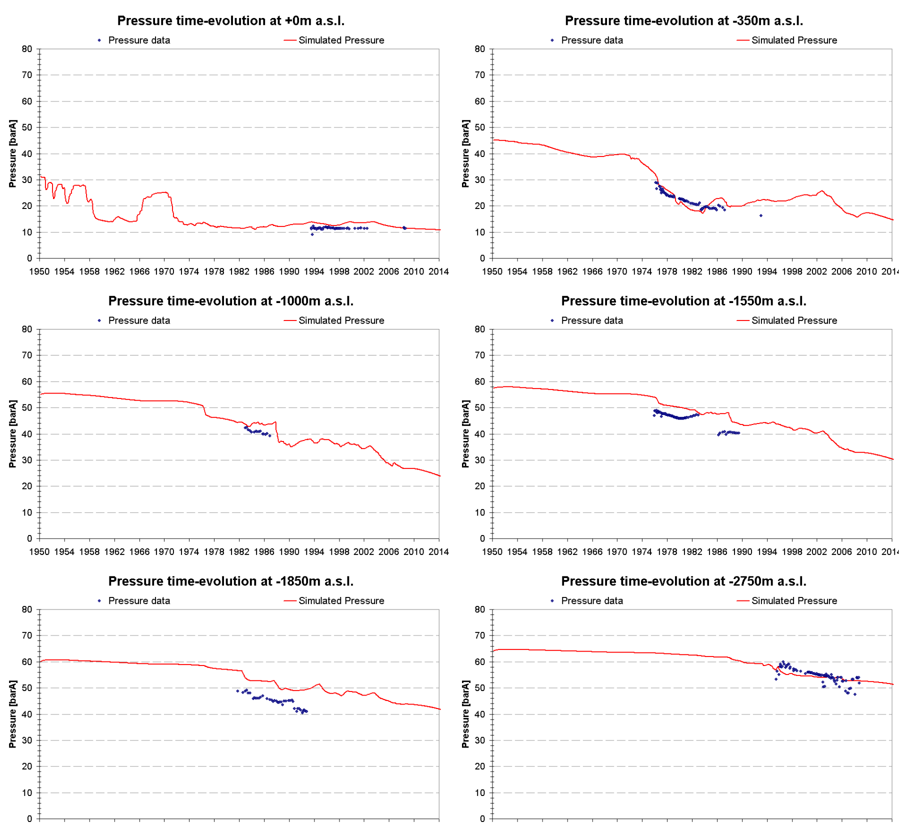

Figure 7. Well pressure evolution with time.

Fairly good results have been obtained both for shallow reservoir pressures and for deeper ones, with one exception at depth of -1850m, where the decrease with time of simulated pressure resulted slower than historical data. This is probably due to local lower permeability value at that depth.

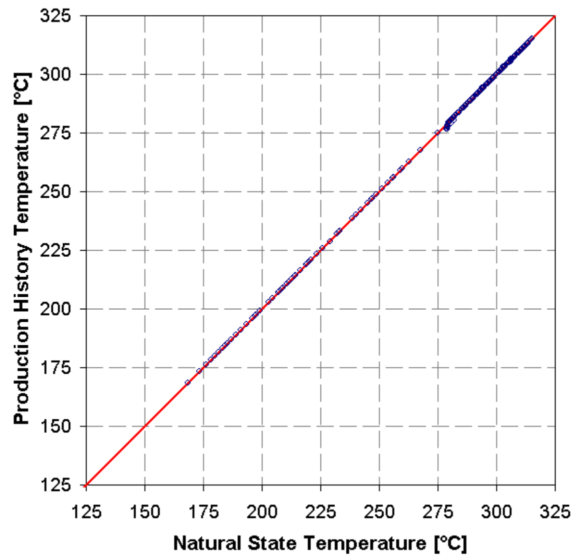

Figure 8. Temperature comparison between natural state and production history.

General Results and Future Field Performance

The most important results for production history are listed below:

- No significant temperature variations are evident during Travale industrial exploitation. Natural state and present state temperatures for each simulation cell at -3000m depth are comparable (Figure 8).
- The simulated pressure distribution for 2008 decreases in the central part of reservoir from the initial 65bar. The pressure of the surrounding deep aquifers does not change significantly, even if a slight pressure decrease could be noticed at the interface between steam dominated reservoir and surrounding aquifers. This pressure decrease is caused by the evaporation of liquid water in the nearness of the steam dominated reservoir. The evaporation of liquid water is due to a decrease in reservoir pressure induced by industrial exploitation. The consequent steam generation assures partial system recharge. Natural state and present state pressures for each simulation cell at -3000m depth are comparable (Figure 9).
- Shallow aquifers are not involved in the recharge mechanism because they are separated from the geothermal system by

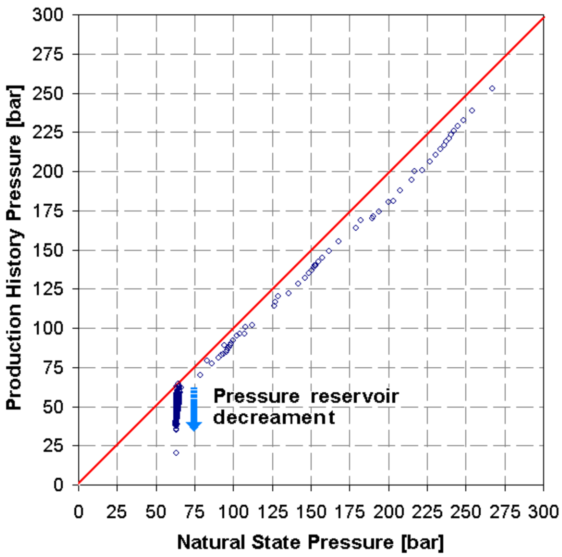

Figure 9. Pressure comparison between natural state and production history.

impermeable layers. The only interaction between these aquifers and the geothermal reservoir is a well-known recharge in correspondence of local outcrops of carbonate formations.

The good results, shown by the simulation of natural state and production history, have allowed using this regional modeling to predict future evolution with time.

Satisfactory results have been achieved and field production results have proved to be sustainable for at least the next 50 years.

Conclusions

This numerical simulation has allowed understanding of the geothermal processes that are at basis of the continuous steam supply in the Travale system. Natural state simulation has been used to tune rock parameters of the model. In particular, rock parameters such as porosity and permeability were changed to optimize simulation results in the comparison between distributions of simulated and observed temperatures and pressures for natural state.

These 3D distributions have been used to simulate field production history and to evaluate future evolution and sustainability. In addition, the historical data of the industrial exploitation have been introduced and the simulation has been performed till 2008. To improve the match of pressure evolution with time, slight variations have been applied to rock parameters.

Fairly good results have been obtained for the comparison between simulated and observed pressure evolution with time at different reservoir depths. Horizontal temperature distributions obtained by production history simulation have shown that no significant temperature variations are evident during industrial exploitation. Pressure distributions for 2008 instead have shown a decrease in the central part of reservoir from the initial 65bar.

The pressure of the surrounding deep aquifers does not change significantly, even if a slight pressure decrease could be noticed at the interface between steam dominated reservoir and surrounding aquifers. This is caused by the evaporation of liquid water in the nearness of the steam dominated reservoir. This steam generation assures partial system recharge accounting for the productive capacity of the Travale geothermal field.

The good simulation results have allowed using this regional model to predict future evolution with time and field production have proved to be sustainable for at least the next 50 years.

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