European Geothermal Congress 2013
Pisa, Italy, 3-7 June 2013

Deep-seated Geothermal Resource Assessment of the VIGOR Project Regions, Italy

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Keywords: geothermal energy, resources assessment, deep aquifers.

ABSTRACT

A performance assessment of deep-seated geothermal systems was carried out in collaboration with TNO (Netherlands Geological Survey) to evaluate at regional scale the geothermal energy potential of the VIGOR Project regions (Southern Italy). Three main components were considered in the analysis: *the resource* – estimating its magnitude and distribution, *the technology* – establishing requirements for extracting and utilizing energy from reservoir including the application to be developed and *the economics* – estimating costs per unit of power produced. The VigorThermoGIS code, based on the volumetric estimation method and Monte Carlo simulations, provided probabilistic estimates of the stored heat, theoretical technical potential and economic technical potential. The results for the Sicily Region are here presented.

1. INTRODUCTION

One of the main goals of the VIGOR Project is the mapping of the deep geothermal potential over broad geographic regions such the results can be directly compared. In collaboration with the TNO, a methodology for estimating and mapping the geothermal potential has been performed and optimized for Italian territory, following the general principles as described by MIT (2006), Blackwell et al. (2007) and van Wees et al. (2010). The VigorThermoGIS output maps are of strategic importance for the evaluation of both geothermal exploitation suitability and successful energy strategies. The required input data are the reservoir geometry, the reservoir permeability, the temperature model and also a set of physical properties of the water-rock system. By evaluating an extensive dataset from hydrocarbon exploratory wells and interpreted seismic reflection profiles, such input parameters were defined to characterise the regional resource and its potential in the Sicily Region.

The structural setting of Sicily is characterized by three main elements: 1) the foreland in the SE-corner (Iblean plateau), representing the Upper Triassic–Early Cretaceous passive continental margin, 2) the Late Pliocene–Pleistocene NW-dipping foredeep along the northern side of the foreland, presently buried below the frontal sector of the chain and 3) the E–SE verging thrust belt, outcropping on land, characterized by an imbricate thrust system to the north, and by a stack of thrusts and nappes to the south (Accaino et al. 2011). These units lie on top of the crystalline basement with depths, inferred by aeromagnetic data, ranging from 10 to 12 km in the westernmost Sicily sector and more than 14 km in the centre of the region. Beneath the Iblean domain the top of the magnetic basement ranges from 8 to 10 km depth (Bello et al. 2000).

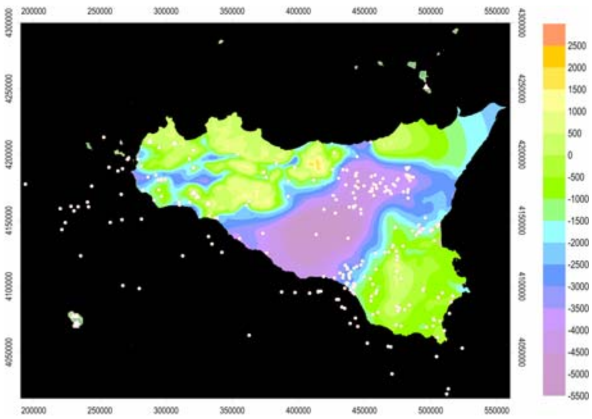

Figure 1: Top of the Mesozoic carbonate units (m b.s.l.) and location of the available deep hydrocarbon exploratory (circles) and the shallow geothermal (triangles) wells.

2. AQUIFER CHARACTERIZATION

The main current accessible deep geothermal resources are represented by hydrothermal, convective systems. At regional scale the Mesozoic carbonate units hold the main aquifers, furthermore local minor aquifers in sandy discontinuous horizons in the overlaying cover units may exist. In favourable geological-structural conditions the circulating geothermal fluids can reach relatively shallow depth, facilitating their exploitation. To obtain an accurate 3D geological representation of the buried geometries

(Fig. 1), an approach based on surface and subsurface data integration with the interpretation of geophysical survey and lithological logs is applied. As the geologic structure of the area is rather complex, a simplified two layers 3D geological model including an impervious clay-rich cap rock above a permeable carbonate reservoir is set up.

2.1 Regional temperature field

Thermal data collected during drilling operations are the only direct evidences of the deep thermal state. More than 1500 temperature data are available from 280 hydrocarbon exploratory wells (Fig. 1) in the depth range 200–5900 m. Nevertheless the bottom hole temperatures (*BHT*) consistently underestimate the formation temperature because the circulating drilling mud is cooler than the surrounding rocks. When the circulation of the drilling mud stops (for example, in preparation for the insertion of a wireline tool), the borehole gradually starts to recover the true formation temperature via heat conduction. This process is slow and the thermal equilibrium may only be attained after several months after drilling operation stops. However if two or more *BHT* readings (at a given depth) from different combination tool runs at different times are available the formation temperature, or static bottom hole temperature (*SBHT*), can be extrapolated. Among several correction methods proposed (Goutorbe et al. 2007, Pasquale et al. 2008), the most common is the Horner plot (Bullard 1947). In the Horner plot method, the thermal effect of drilling is approximated by a constant linear heat source:

$$BHT(t_c, \Delta t) = SBHT + \frac{Q}{4\pi\lambda}\log\left(1+\frac{t_c}{\Delta t}\right) \qquad [1]$$

where Q is the heat supplied per unit length and unit time, λ the thermal conductivity of the mud-rock system, t_c the length of time that the borehole was subjected to the cooling effect of the circulating drilling mud and Δt the time after circulation that the borehole has had to partially recover the formation temperature. The equation [1] represents a straight line when *BHT* data are plotted against the dimensionless Horner time, whose extrapolation to $\Delta t \to \infty$ yields the formation temperature. In accordance to other authors, the formation temperature can be estimated with an uncertainty of ±10%.

For each well having two or more temperatures, the geothermal gradients inside the cover and reservoir units are computed by the ordinary least squares method (Fig. 2). Since the boreholes are not homogeneously distributed on the territory, to map the geothermal gradients a geostatistical interpolation method (krigging) is applied. On the basis of the geological model and geothermal gradient contour maps for the cover and reservoir units, the temperature field has been computed on a three-dimensional meshgrid of size 1000 x 1000 m along latitude and longitude and 100 m in depth. The topography and the mean annual air temperature variations have been taken into account, the base of the model was fixed to 5 km b.s.l.

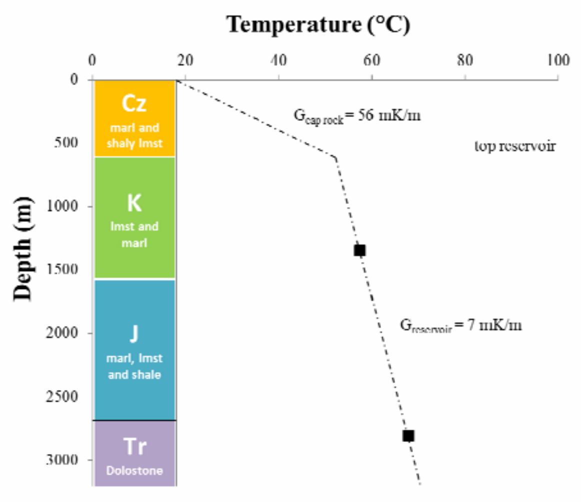

Figure 2: Temperature data analysis and geothermal gradients along Bimmisca 1 well.

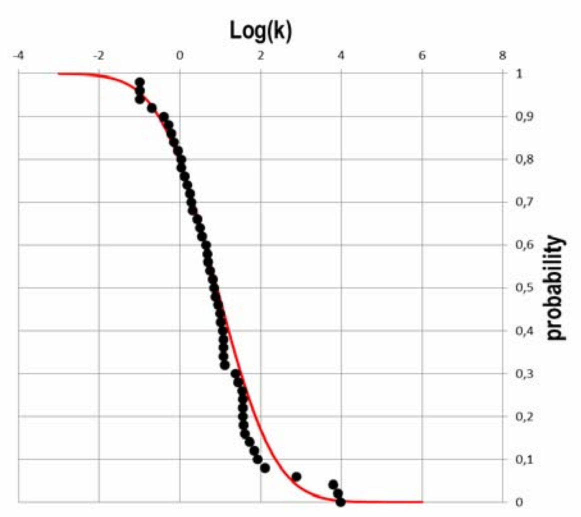

Figure 3: Lognormal distribution of permeability inferred from DST.

2.1 Reservoir permeability

Permeability of porous media in subsurface is subject to potentially large uncertainties due to the heterogeneity of natural systems. Founded on Dupuit approximations, a first order of magnitude of the reservoir permeabilities are derived from the results of drill-stem tests done for hydrocarbon exploration. A Drill Stem Test (DST) uses packers lowered on drillpipe, upon reaching the depth at which the test is to take place the packers are expanded allowing pressure isolation of the selected interval. Once the packers have been seated and the tester valve opened, the pressure in the portion of the hole below the packer rapidly drops toward atmospheric and fluid begins to move from the formation into the drill stem. Normal testing procedure calls for two opening and closing of the tester valve. After each flow period the tester valve is closed so that the shut-in-pressure buildup can be recorded. DSTs provide confirmation on the type of fluid in the tested intervals, laboratory analyses on fluid samples yield their physical/chemical properties and from interpretation of pressure measurements the formation permeabilities can be evaluated. The results show that in the fractured carbonate reservoir the permeability values do not follow an evident trend with depth. Instead has been shown that permeabilities exhibit a lognormal distribution (Fig. 3).

3. GEOTHERMAL RESOURCE ASSESSMENT

The VigorThermoGIS maps of the key performance indicators have been calculated at a grid spacing of 1 km. They represent a progressive filtering approach starting from the total heat stored in the deep-seated reservoir to the evaluation of the heat which can extracted from the aquifer under technical and economic constraints. The basic assumption is that energy is extracted from hot water by a doublet, that is an injection and a production well.

First step is the evaluation, based on the volumetric estimation method, of the heat in place (HIP) corresponding to the maximum theoretically extractable heat in the aquifer in PJ km^{-2}. For each cell of 1 km^2, the HIP is proportional to the heat capacity of the water-rock system, the reservoir thickness and the temperature difference at depth and at surface. Second step is the evaluation of the theoretical capacity (TC) corresponding to the heat which can be recovered from the reservoir in PJ km^{-2} (Fig. 4). Assuming that the recoverable heat is about 33% of HIP (van Wees et al. 2012), TC is computed tacking into account the minimum temperature required and the energy conversion efficiency for a specific application (Table 1). Consequently, TC is a subset of HIP as, depending on required production temperature, particular areas will not available. Third step is the evaluation for each application of the technical potential (TP) in MW km^{-2} (Fig. 5), assuming that the TC can be typically produced over 30 years. Last step is the evaluation for each application of the economic-technical potential (TP_LCOE) in MW km^{-2} (Fig. 6) under some assumptions (Table 1). The TP_LCOE predicts favorable areas where thermal power can be produced tacking into account both technical and economic aspects. The doublet performance is strongly dependent on reservoir properties (thickness, pressure, flow rate, permeability) and Monte Carlo simulations have been used for performance calculation (the result are obtained for P90, P50 and P10 values of transmissivity). The economic performance of the geothermal project is based on the levelized cost of energy (LCOE). LCOE is the constant unit cost (per MWh) of a payment stream that has the same present value as the total cost of a generating plant over its life.

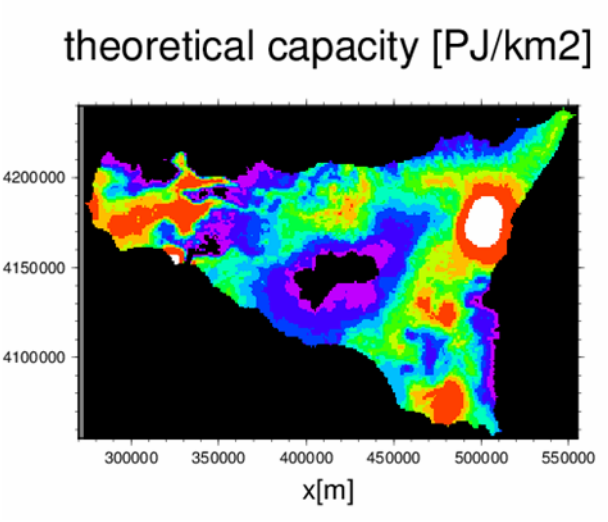

Figure 4: Theoretical capacity map (district heating).

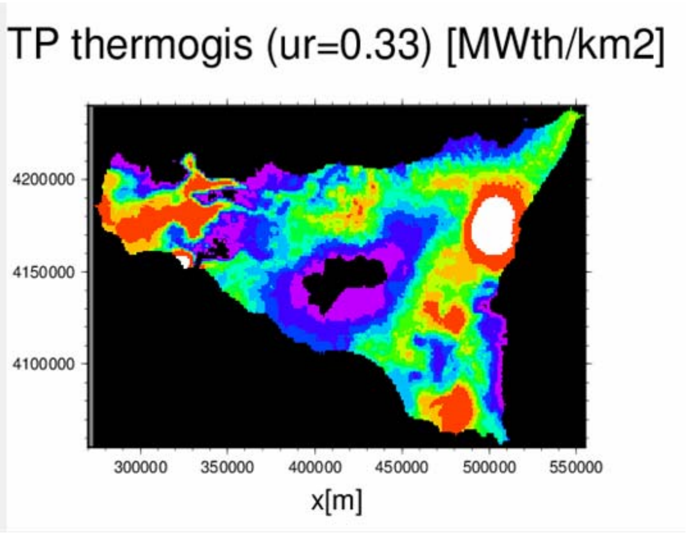

Figure 5: Technical potential map (district heating).

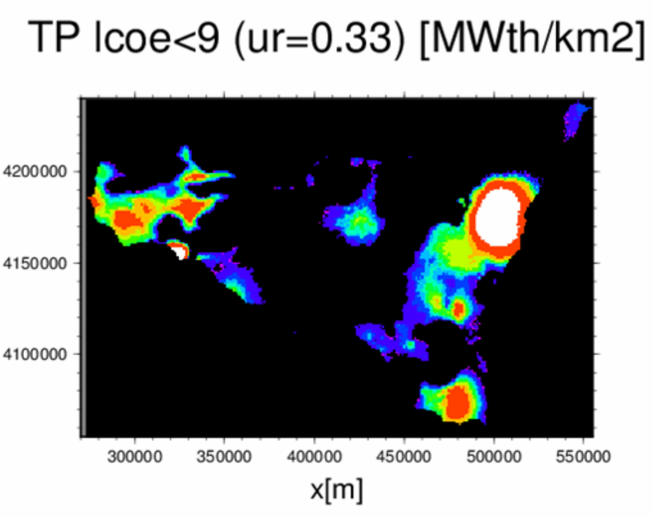

Figure 6: Economic-Technical potential map (district heating) for the P50 transmissivity.

Table 1: Application assumptions

	Power	District heating	Direct heat
Minimum temperature	120	80	45
Injection temperature	97	40	35
Economic model	power	heat	heat
Threshold LCOE	200 €/MW	9 €/GJ	9 €/GJ

4. CONCLUSIONS

The obtained results will be useful for the planning and development of geothermal power production on a regional and national scale, and also for defining characteristics of research and demonstration projects in suitable sites. VIGOR wants to be an example of a truly comprehensive geothermal assessment, to be followed in other regions, to answer energy demand and for future benefit of society.

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Acknowledgements

The present activity has been performed in the frame of the VIGOR Project, aimed at assessing the geothermal potential and exploring geothermal resources of four regions in southern Italy. VIGOR is part of the activities of the Interregional Programme "Renewable Energies and Energy Savings FESR 2007-2013 – Axes I Activity line 1.4 "Experimental Actions in Geothermal Energy". The authors acknowledge the management of VIGOR Project, and in particular Dr. Piezzo of MiSE-DGENRE (Directorate General for Nuclear Energy, Renewable Energy and Energy Efficiency of the Ministry for Economic Development), Dr. Brugnoli, Director of CNR-DTA (National Research Council of Italy, Department of Sciences of the Earth System and Environmental Technologies) and the coordinator, Dr. Manzella of CNR-IGG.