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

3D geological modelling of a fractured carbonate reservoir for the study of medium enthalpy geothermal resource in the Southern Apennines (Campania Region, Italy)

Barbara Inversi[(1)(2)], Davide Scrocca[(1)], Giordano Montegrossi[(3)], Michele Livani[(1)(2)], Lorenzo Petracchini[(1)(4)], Marco Brandano[(2)], Mauro Brilli[(1)], Francesca Giustini[(1)], Riccardo Recanati[(1)], Gianluca Gola[(3)], Maurizio Polemio[(6)], Alessandro Romi[(5)], Roberto De Franco[(7)], Grazia Caielli[(7)], Bruno Testa[(7)].

(1) Istituto di Geologia Ambientale e Geoingegneria – CNR

(2) Dipartimento di Scienze della Terra, Sapienza Università di Roma

(3) Istituto di Geoscienze e Georisorse – CNR

(4) Dipartimento di Scienze della Terra, Università di Bologna

(5) Schlumberger Information Solutions, Schlumberger

(6) Istituto di Ricerca per la Protezione Idrogeologica - CNR

(7) Istituto per la Dinamica dei Processi Ambientali - CNR

Barbara Inversi: barbara.inversi@igag.cnr.it, +39 3394156636

Keywords: 3D Model, Geothermal resource, medium enthalpy, Southern Apennines**.**

ABSTRACT

A characterization of medium enthalpy geothermal resources has been carried out in the Southern Apennines "Guardia Lombardi" site (Campania Region, Italy) within the framework of the Vigor Project.

Due to the intense hydrocarbon exploration carried out in Italy since the '50, a wide public dataset of well data and seismic reflection profiles is available for the study site. Moreover, a scientific cooperation with the ENI Italian Oil Company has been established in order to access to more detailed dataset also including wells information and core samples.

A three-dimensional geological model of the reservoir-caprock system has been developed through an integrated interpretation of the available geological, geophysical, hydrogeological and geochemical information in the study area.

The geothermal reservoir of "Guardia Lombardi" site is constituted by the Cretaceous-Eocene fractured shallow water carbonates belonging to the Apulian platform. Such units have been structured in a buried antiformal stack during the Apennine orogenesis.

The reservoir fluids are mainly composed of CO_2, which rests above of brackish water in the central part of the deep carbonatic aquifer culmination (i.e., Monte Forcuso 1 well). Conversely along the flanks of the buried anticline (e.g., Bonito 1 Dir, Ciccone 1 wells) the reservoir fluids consist of saline water, not showing any free gas phase. The temperature of this fluids recorded into the reservoir are 120-125°C at the depth of about 3000 m below the ground level (e.g. Bonito 1 well).

Given the quite good permeability of the fractured carbonate rocks, numerical simulation performed in this work estimated that a water production of about 13.5-20 kg/s might be achieved according to the chosen technical solution (a single production well vs production- reinjection doublet).

Results confirm that the "Guardia Lombardi" site represents an interesting area for the exploitation of this medium enthalpy geothermal resource.

1. INTRODUCTION

The main aim of the Vigor project, funded by the Italian Ministry of Economic Development following an agreement with the Italian National Research Council, was to evaluate the geothermal potential and to promote the innovative exploitation of geothermal resources in non-volcanic areas in the so-called "regions of convergence" in southern Italy (Campania, Calabria, Puglia and Sicilia).

The "Guardia Lombardi" site has been chosen for this project because it shows evidences documenting the presence of a thermal anomaly in the subsurface (fig. 1). These evidences are following:

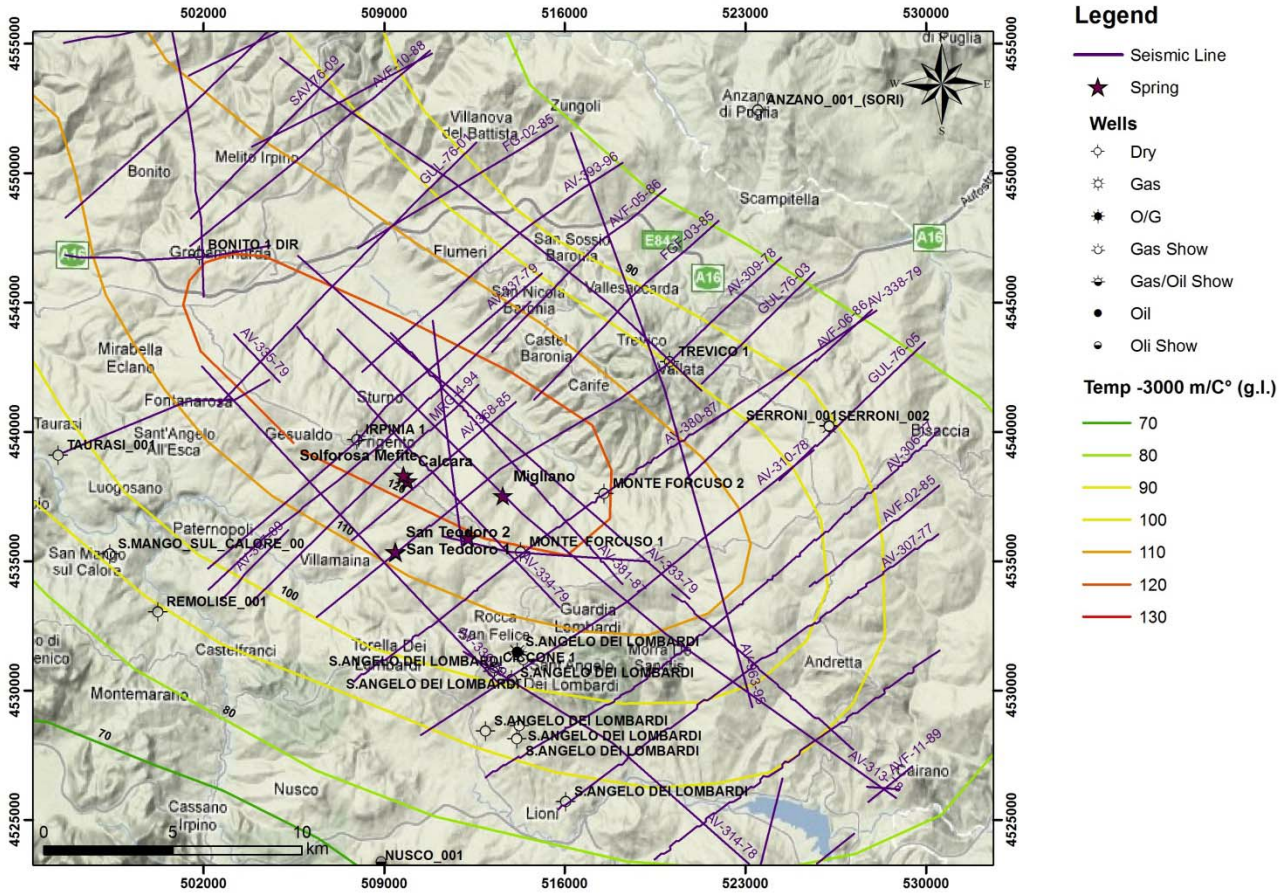

Figure 1: Base-map of "Guardia Lombardi" site that show topography, location of wells, springs and seismic profile and the thermal anomaly at -3000 m depth from the ground level.

- high heat flow (90 mW/m^2) (Della Vedova et al., 2001);

- temperatures measured in wells in a range between 100° and 120°C at 3000 m depth below the ground level (ENEL, 1987; ENEL/ENI/CNR/ENEA, 1994; Della Vedova et al., 2001);

- hot water with temperature around 27°-29°C captured at around 30 m depth (e.g. San Teodoro's thermae; Ortolani et al., 1981; Budetta et al., 1988);

- presence in the Mefite d'Ansanto spring of a huge natural emission of low temperature CO_2 rich gases (total gas flux 23.1 kg/s - 2000 ton/day; Chiodini et al., 2010).

- geothermometers on water samples collected from thermal springs estimate a reservoir temperature of 124˚C (Duchi et al., 1995).

Between the 1950 and 1970 the area has been interested by an intense hydrocarbons exploration phase (e.g., Mostardini and Merlini, 1986; Turrini and Rennison, 2004; Nicolai and Gambini, 2007; Patacca and Scandone, 2007; Bertello et al,. 2010). This activity has made available a conspicuous number of information (seismic profile, composite well logs, etc.,) about the geological and structural setting of the area, also highlighting its potential in terms of uptake of medium-enthalpy geothermal fluids.

2. GEOLOGICAL SETTING

The Southern Apennines fold and thrust belt developed during Neogene and the Quaternary times along the eastward-retreating west-directed subduction of the Apulo-Adriatic lithosphere (Scrocca, 2010).

The development of the Southern Apennines accretionary prism occurred through the off-scraping and incorporation at the subduction zone of the Meso-Cenozoic sedimentary covers (essentially pelagic units and shallow water carbonates) located along the Apulo-Adriatic passive margin, and associated active margin deposits.

In the paleogeographic model adopted in this work, the main Mesozoic domains are the following (for details, see Scrocca, 2010 and references therein): i) the internal nappes of the Liguride-Sicilide basin, ii) the Apennine carbonate platform, iii) the Lagonegro

and Molise basins and iv) the Apulian carbonate platform.

Since the Early Miocene, the accretionary prism migrated from west to east. Contractional deformations were followed by coeval extensional faulting which, progressively, cross-cut the thrust pile (among many others, Mostardini and Merlini, 1986; Casero et al., 1988; Patacca et al., 1990; Patacca and Scandone, 2007; Scrocca et al., 2005; Scrocca 2010 and references therein) .

The structural setting of the "Guardia Lombardi" area is characterized by buried thrust-related folds, developed during the Apennine orogenesis in Pliocene times, offset by extensional faults during Pleistocene times. Several interpretation have been proposed to explain this sector of the Southern Apennines and its geological and geodynamical setting (e.g., Ciaranfi et al., 1973; Ippolito et al., 1974; Bonardi et al., 1988; Dazzaro et al., 1988; Torre et al., 1988; Consiglio Nazionale delle Ricerche, 1992; Pescatore et al., 1999; Basso et al., 2001; Matano and Di Nocera, 2001; Di Nocera et al., 2002, 2006; Patacca and Scandone, 2007; Pescatore et al., 2007; Bonardi et al., 2009; Vezzani et al., 2010; Di Nocera et al., 2011).

3. GEOTHERMAL RESOURCE

The geothermal reservoir consists of fractured limestones (Cretaceous-Eocene) belonging to the Apulian shallow water carbonate platform.

The structural setting of the reservoir is characterized by buried thrust-related folds, developed during the Apennine orogenesis in the Pliocene time, offset by extensional faults during the Pleistocene time.

In the study area, the geothermal reservoir shows several structural culminations (fig. 2); the shallower one is located at a depth of -1125 m below the ground level (~250 m SSL) in correspondence of Monte Forcuso 1 well.

Matrix porosity of reservoir rocks is generally low but the presence of fractures and faults improve significantly the poro-perm properties. In the highly fractured intervals the permeability porosity product may reach values of about 100-150 mD.

The reservoir fluids are mostly made by CO_2 and brackish water. Essentially, the Monte Forcuso structural culmination is filled by a CO_2 gas cap, which develops for several hundred meters. Further below there is an accumulation of brackish water. The study of the composite well logs of the Guardia Lombardi area allow the definition of the CO_2 gas cap areal extent and its depth. Along the flanks of the Monte Forcuso culmination and in the other deeper structural highs (e.g., the one drilled by Bonito 1 well) the CO_2 gas cap is not developed and the reservoir fluid is made up by saline water.

The available temperatures extracted by the composite well logs and ENEL documentation (1987,1994) have been corrected using different techniques. These data show temperature up to 120-125°C at the depth of about 3000 m below the ground level (Bonito1 Dir well).

Reservoir fluid pressure recorded in the Bonito 1 Dir well is essentially hydrostatic. Furthermore, the few pressure data available in the rest of the study area suggests an hydraulic connection in the whole reservoir.

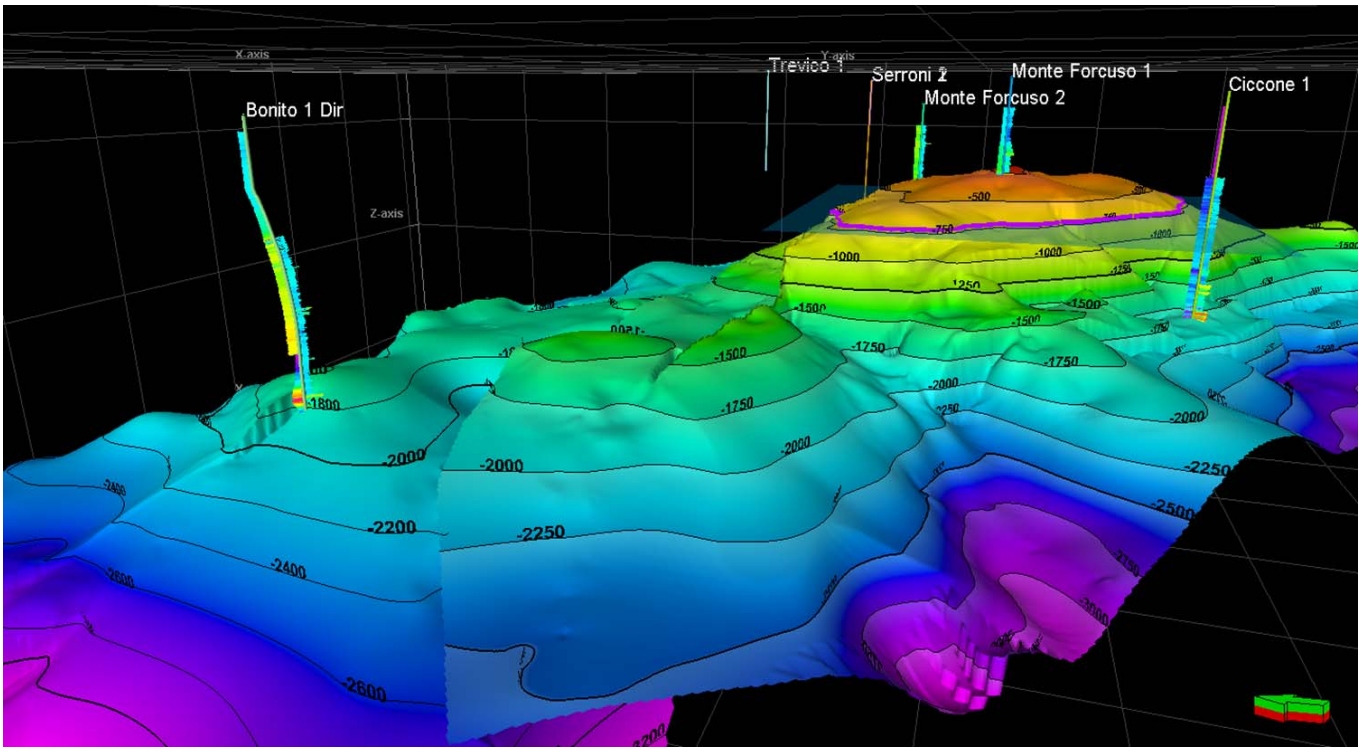

Figure 2: Tri-dimensional geological model of the geothermal reservoir (Apula platform fractured carbonates) structural culmination below the area of the "Guardia Lombardi" site. The purple line locates the CO2/water contact.

Detailed seismic interpretation allow to hypothesize that the main structural units follow a main NW-SE trend, with a secondary system oriented NE-SW.

6. CONCLUSIONS

A detailed 3D reconstruction of the structural and geological setting of the geothermal reservoir-caprock system of "Guardia Lombardi" site have been obtained through an integrated analysis of all the information collected during this work (fig. 2).

Moreover, a numerical simulation of the "Guardia Lombardi" site have been performed using the thermal capacity of the carbonate rocks (Montegrossi et al., 2008) to define the reservoir material properties. Such preliminary results will be however fully discussed in a separate paper.

Relying on the conceptual model and on the simulation results, a possible scenario with a single production well vs production-reinjection doublet was developed for the exploitation of the "Guardia Lombardi" thermal resource.

REFERENCES

Basso, C., Di Nocera, S., Esposito, P., Matano, F., Russo, B. and Torre, M.: Stratigrafia delle successioni sedimentarie evaporitiche e post – evaporitiche del Messiniano superiore in Irpinia settentrionale (Appennino meridionale, Italia). *Bollettino della Società Geologica Italiana*, **120**, (2001), 211-231.

Bertello, F., Fantoni, R., Franciosi, R., Gatti, V., Ghielmi, M. and Pugliese, A.: From thrust and folt belt to foreland: hydrocarbon occurrences in Italy. In: Vining B.A. & Pickering, (eds), Petroleum Geology: From Mature Basins to New Frontiers – *Proceedings of the 7th Petroleum Geology Conference 2010*, 113–126. DOI: 10.1144/0070113.

Bonardi, G., D'Argenio, B. and Perrone, V.: Carta geologica dell'Appennino meridionale. *Memorie della Società Geologica Italiana*, **41**, (1988), 1341.

Bonardi, G., Ciarcia, S., Di Nocera, S., Matano, M., Sgrosso, I. and Torre M.: Carta delle principali unità cinematiche dell'Appennino meridionale. Nota illustrativa. *Bollettino della Società Geologica Italiana*, **128**, (2009), 47-60.

Budetta, P., Celico, P., Corniello, A., De Riso, R., Ducci, D. and Nicotera, P.: Carta idrogeologica del F. 186 (S. Angelo dei Lombardi) memoria illustrativa. *Memorie della Società Geologica Italiana*, **41**, (1988), 1029-1038.

Casero, p., Rouge, F., Endignoux, L., Moretti, I., Muller, C., Sage, L. and Vially, R.: Neogene geodynamic evolution of the Southern Apennines. *Memorie della Società Geologica Italiana*, **41**, (1988), 109-120.

Chiodini, G., Granieri, D., Avino, R., Caliro, S., Costa, A., Minopoli, C. and Vilardo, G.: Non-volcanic CO2 Earth degassing: Case of Mefite d'Ansanto (southern Apennines), Italy. *Geophysical Research Letters*, **37**, (2010), L11303, doi:10.1029/2010GL042858.

Ciaranfi, N., Dazzaro, L., Pieri, P., Rapisardi, L. and Sardella, A.: – Geologia della zona compresa fra Bisaccia (Avellino) ed il T Olivento, presso Lavello (Potenza). *Memorie della Società Geologica* Italiana, **12**, (1973), 279-315.

Dazzaro, L., Di Nocera, S., Perscatore, T.S., Rapisardi, L., Romeo, M., Russo, B., Senatore, M.R. and Torre, M.: Geologia del margine della catena Appenninica tra il F. Fortore ed il T. Calaggio (Monti della Daunia – Appennino Meridionale). *Memorie della Società Geologica Italiana*, **41**, (1988), 411-422.

Della Vedova, B., Bellani, S., Pellis, G. and Squarci, P.: Deep temperatures and surface heat flow distribution. In: Vai GB, Martini IP (eds), Anatomy of an orogen: the Apennines and adjacent Mediterranean basins, 65–76, *Kluwer*, Dordrecht, (2001).

Di Nocera, S., Matano, F. and Torre, M.: Le unità "sannitiche" Autc. (Appennino centro – meridionale): rassegna delle correnti interpretazioni stratigrafiche e paleogeografiche e nuove ipotesi con l'introduzione dell'Unità del Frigento. *Studi Geologici Camerti*, **1**, (2002), 87-102.

Di Nocera, S., Matano, F., Perscatore, T.S., Pinto, F., Quarantiello, R., Senatore, M.R. and Torre, M.: Schema geologico del transetto Monti Picentini orientali – Monti della Daunia meridionali: unità stratigrafiche ed evoluzione tettonica del settore esterno dell'Appennino meridionale. *Bollettino della Società Geologica Italiana*, **125**, (2006), 39-58.

Di Nocera, S., Matano, F., Pescatore, T.S., Pinto, F. and Torre, M.: Caratteri geologici del settore esterno dell'Appennino campano – lucano nei fogli CARG. *Rendiconto online della Società Geologica Italiana*, **supplemento 12**, (2011), 39-43.

Duchi, V., Minissale, A., Vaselli, O. and Ancillotti, M.: Hydrogeochemestry of the Campania region in southern Italy. *Journal of Volcanology and Geothermal Research*, **67**, (1995), 313-328.

Enel: Inventario delle risorse geotermiche nazionali: Regione Campania. Rapporto Tecnico, (1987), 53 pp., 8 tav. Disponibile sul sito web dell'UNMIG, ultimo accesso il 2 marzo 2012, http://unmig.sviluppoeconomico.gov.it/unmig/geotermia/inventario/rapporto.asp?id=6.

Enel/Eni/Cnr/Enea: Inventario delle risorse geotermiche nazionali. Valutazione del potenziale geotermico nazionale (1994). Aggiornamento 1994. Rapporto Tecnico, 194 pp., 6 tav. Disponibile presso il sito web dell'UNMIG, ultimo accesso il 2 marzo 2012, http://unmig.sviluppoeconomico.gov.it/unmig/geotermia/inventario/rapporto.asp?id=14.

Ippolito, F., Ortolani, F. and Di Nocera, S.: Alcune considerazioni sulla struttura profonda dell'Appennino Irpino: reinterpretazione di ricerche di idrocarburi. *Bollettino della Società Geologica Italiana*, **93**, (1974), 861-881.

Matano, F. and Di Nocera, S.: Geologia del settore centrale dell'Irpinia (Appennino Meridionale): nuovi dati e interpretazioni. *Bollettino della Società Geologica Italiana*, **120**, (2001), 3-14.

Mostardini, S. and Merlini, S.: Appennino centro-meridionale. Sezione deologiche e proposta di modello strutturale. *Memorie della Società Geologica Italiana*, **35**, (1986), 177-202.

Montegrossi, G., Cantucci, B., Vaselli, O. and Quattrocchi, F.: Reconstruction of porosity profile in an off-shore well. *Bollettino di Geofisica Teorica ed Applicata*, **49**, (2008), 408-410.

Ortolani, F., De Gennaro M., Ferreri M., Ghiara M.R., Stanzione D. and Zenone F.: Prospettive geotermiche dell'Irpinia centrale (Appennino meridionale): studio geologico-strutturale e geochimico. *Bollettino della Società Geologica Italiana*,**100**, (1981), 139-159.

Nicolai, C. and Gambini, R.: Structural Architecture of the Adria Platform and Basin System. *Bollettino della Società Geologica Italiana*, **7**, (2007), 21-37.

Patacca, E., Sartori, R., and Scandone, P.: Tyrrhenian basin and Apenninic arcs: kinematic relations since late Tortonian times. *Memorie della Società Geologica Italiana*, **45**, (1990), 425-451.

Patacca, E. and Scandone, P.: Geology of the Southern Apennines. *Bollettino della Società Geologica Italiana*, **7**, (2007), 75-119.

Pescatore, T., Renda, P., Schiattarella, M. and Tramutoli, M.: Stratigraphic and structural relationships between Meso-Cenozoic Lagonegro basin and coeval carbonate platforms in the Southern Apennines, Italy. *Tectonophysics*, **315**, (1999), 269-286.

Pescatore, T.S., Di Nocera, S., Matano, F., Pinto, F., Quarantiello, R., Amore, O., Boiano, U., Civile, D., Fiorillo, L. and Martino, C.: Geologia del settore centrale dei monti del Sannio: nuovi dati stratigrafici e strutturali. *Memorie Descrittive della Carta Geologica d'Italia***, LXXVII**, (2007), 77-94.

Scrocca, D., Carminati, E. and Doglioni, C.: Deep Structure of the Southern Apennines, Italy: Thin – Skinned or Thick Skinned?. *Tectonics*, **24**, (2005), doi: 10.1029/2004TC001634.

Scrocca, D.: Southern Apennines: Structural Setting and Tectonic Evolution. *Journal of the Virtual Explorer*, **36**, (2010), paper 14, doi: 10.3809/jvirtex.2010.00225.

Turrini, C. and Rennison, P.: Structural Style from the Southern Apennines' Hydrocarbon Province. An integrated view, in K. R. McClay, ed., *Thrust tectonics and hydrocarbon system American Association of Petroleum Geologists Memoir*, **82**, (2004), 558 – 578.

Torre, M., Di Nocera, S. and Ortolani, F.: Evoluzione post – tortoniana dell'Appennino meridionale. *Memorie della Società Geologica Italiana*, **41**, (1988), 47-56.

Vezzani, L., Festa, A. and Ghisetti, F.C.: Geology and tectonic evolution of the Central-Southern Apennines, Italy. *Geological Society of America*, Special Papers 2010, **469**, (2011), 1-58, doi: 10.1130/2010.2469.

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) and 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.