THE HISTORICAL GEOTHERMAL INVESTIGATIONS OF CAMPANIAN VOLCANOES: CONSTRAINS FOR MAGMA SOURCE LOCATION AND GEOTHERMAL POTENTIAL ASSESSMENT

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The Campania region is characterized by the presence of the active volcanoes of Phlegrean district (Campi Flegrei and Ischia calderas), west to the city of Naples, and Somma-Vesuvius to the east. Most of this area is marked by the occurrence of anomalous high heat flow and temperature at very shallow depth (*Geothermal gradient*: 150-200°C at Campi Flegrei and Ischia respectively; 30°C/km at Vesuvius. *Heat flow*: Mofete, 160mWm^{-2}; S.Vito and Mt.Nuovo, 160mWm^{-2}; Agnano:120 mWm^{-2}; Ischia western and southern sector, 560-580mWm^{-2}). These features are related to different causes: the rising of the Moho (~ 20 km of depth) and the thinning of the crust in the central part of the Tyrrhenian Basin, due to the spreading of the sea floor; the migration of magma at a minimum depth of 8-10 km due to the buoyancy forces; the geothermal fluids circulation above the magmatic sources. The study of the geothermal systems of Campanian volcanoes represents an important tool for the understanding of volcano dynamic and associated risk, and also for the quantification of the geothermal potential for thermal and electric energy production.

Pioneering researches of geothermal resources were carried out in Campanian region since 1930. Such researches were part of the Energy National Plan, aimed to better constrain the geothermal potential in the volcanic district of Campania (Vesuvius, Campi Flegrei caldera and Ischia Island), and were supported by a Joint Venture between ENEL and AGIP Companies. The exploration program was stimulated also by the interesting results of geothermal exploitation obtained at Larderello (Tuscany), since the early 1900.

From 1930 to the mid '80, a total of 117 wells for geothermal exploration were drilled down to a maximum depth of 3046 m (90 wells at Ischia, 26 at Campi Flegrei and 1 at Vesuvius). The results of such investigations were particularly encouraging at Campi Flegrei and Ischia, where elevated geothermal gradients were recorded, due to the presence of high enthalpy fluids (T>180°C) locat-

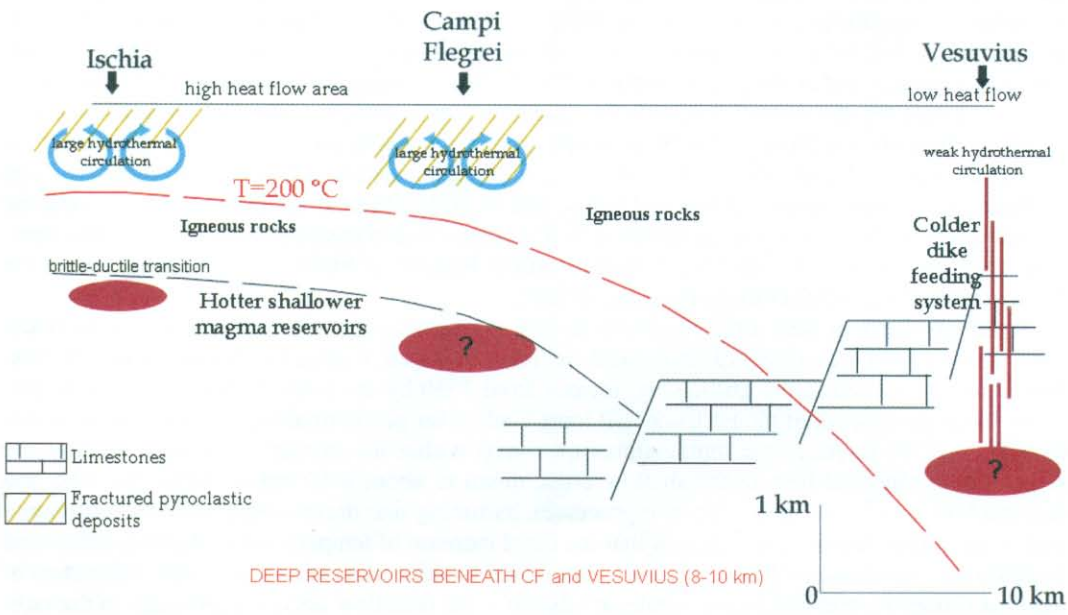

Fig. 1 - Sketch of the shallow crust beneath Campanian volcanoes along a section from Ischia to Vesuvius deduced from gravity, seismic and wells data. It is reported the regional 200°C isotherm and the depth of the brittle to ductile transition (T> 350°C).

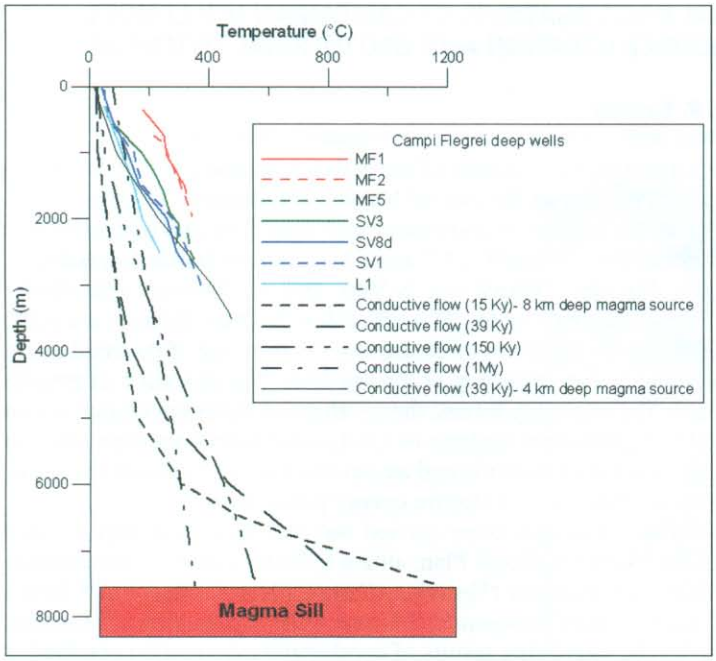

Fig. 2 - An example of comparison among conductive curves (for different time of sill emplacement) with the temperatures measured in the deep wells at Campi Flegrei. The conductive temperature-depth curves are obtained for different times, which correspond to 15 ky (NYT eruption), 39Ky (CI eruption), (150 ky, older Ignimbrite eruptions), 1 My (older volcanic activity of Campania volcanism). The comparison of the obtained curves with the measured temperatures-depth profile of the wells, shows that a conductive heat transport, also acting at the longer time scale, is not sufficient to get the nowadays thermal state of the shallow crust, also assuming a shallow magma source (4 km). The thermal state outside the caldera could be mainly linked to the long term conductive heat propagation from the deep source, while the higher gradients within the caldera are related to hot fluids circulation.

ed at shallow depths (hundred of meters) and both systems vapor and water dominated. Despite these interesting results, the possibility of exploitation of the Campanian geothermal resource was definitively abandoned at mid-'80. In 1950, a prototype binary plant was installed at Ischia, with a power supply of 300kW, and soon abandoned. The main reason of the abandon can be ascribed to the technical problems related to the presence of hyper-saline fluids. The progress performed during extensive researches carried out by the American Electric Power Research Institute and several private companies, have shown the possibility to use these aggressive fluids for generation of electricity in a reliable and cost-effective manner. The drillings program at Campanian volcanoes stimulated not only the geothermal research for industrial application, but also the researches in volcanology. Important information such as temperatures of shallow crust, chemical rocks and fluid composition at depth and stratigraphy have been utilized for the reconstruction of eruptive history of Vesuvius, Campi Flegrei caldera and Ischia and to build physical models. In recent times, the attention paid to the geothermal potential of the Campania region has been drawn back consequently to the launch of the "Campi Flegrei Deep Drilling Project" (CFDDP), in the framework of the International Continental Drilling Program (ICDP).

In this work we present a review of the history of geothermal researches at Campanian volcanoes, starting from the earlier volcanological studies at Vesuvius, Campi Flegrei and Ischia. We analyzed the data related to the drillings performed from 1930 by the SAFEN Company and successively in the framework of the ENEL-AGIP Joint Venture for geothermal exploration. The available data are utilized to relate the temperatures measured within the deeper wells with the possible sources of geothermal heat in the shallow crust, down to about 8-10 km of depth. We take into account both conductive and advective processes, assuming one dimensional unsteady heat transport in an infinite region. We highlight that the rapid increase of temperature *vs* depth is influenced by different mechanisms of heat transport, dominated by advection processes at few kilometers of depth at Campi Flegrei and Ischia, while, at Vesuvius, the heat flow decreases strongly in the radial direction, showing that the hydrothermal circulation is confined in the crater axis, and that conductive processes have a primary role in the heat transfer (Figs. 1 and 2). Finally, we assess the geothermal potential of Ischia and Campi Flegrei, which have shown the best data and favorable phys-

ical conditions for a reliable, and cost-effective, exploitation for thermal and electric purposes. The geothermal potential is evaluated by using the empirical "volume method" developed by Muffler and Cataldi (1978), which takes into account the total geothermal heat stored into a certain volume of rocks and fluids. Our studies are also preparatory for the realization of the "Campi Flegrei Deep Drilling Project" (CFDDP), sponsored by the International Continental Drilling Program (ICDP), aimed to the understanding of the Campi Flegrei caldera dynamics and to accurate geothermal resource assessment.

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THE CAMPI FLEGREI DEEP DRILLING PROJECT 'CFDDP': UNDERSTANDING THE MAGMA-WATER INTERACTION AT LARGE COLLAPSE CALDERAS

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Campi Flegrei caldera is a good example of the most explosive volcanism on the Earth, a potential source of global catastrophes. Alike several similar volcanic areas (Yellowstone and Long Valley, USA; Santorini, Greece; Iwo Jima, Japan, etc.) its volcanic activity, i.e. eruptions and unrests, is dominated by physical mechanisms involving the strict interaction between shallow magma sources and geothermal systems. Furthermore, just like similar areas, it should be characterised by very large shallow magma chambers, filled by residual magma left after the ignimbritic caldera forming eruptions. However, neither the physical mechanisms of magma-water interaction, nor the evidence for such large magma chamber, have been yet clear enough to be used for detailed volcanological interpretation and eruption forecast. Campi Flegrei caldera, with respect to many similar area, has the advantage that the most interesting structural details and main volcanic features appear located at shallower depth, making it a natural candidate for a deep drilling project aimed to understand the volcanic structure of calderas. The CFDDP project, sponsored by ICDP (International Continental Drilling Program), aims to understand, for the first time, the location and rehology of large residual magma chambers and the mechanisms of interaction between magma and aquifer systems to generate eruptions and unrests ay large collapse calderas. CFDDP is then structured as a large multidisciplinary project, with the main goal of volcanic risk understanding and mitigation, and a further goal to launch geothermal energy exploitation at this and other volcanic areas of Italy. A broader goal of the CFDDP project is to establish at Campi Flegrei, a densely urbanised area in a developed western country, a natural laboratory to study volcanic risk, environmental and technology issues, geothermal energy exploitation.

CFDDP is then a multi-purpose, multidisciplinary project involving cooperation of several international Institutions. Because of its complexity and the involvement of drilling activities and logistic solutions, besides a reliable scientific planning it also required optimal solutions to several administrative and communication problems, generally out of the routine activities of a public research Institution. For these reason, new experience has been gained by the involved Institutions about administrative, normative and logistic solutions, which can be highly valuable for the Italian geophysical community to plan and manage future, large multi-disciplinary projects.