HYDROTHERMAL SYSTEM INFLUENCING SLOPE-SCALE DEFORMATIONS AT MT. NUOVO (ISCHIA, SOUTHERN ITALY): PRELIMINARY RESULTS FROM 2D-MULTIPHYSICS NUMERICAL MODELLING

G.M. Marmoni¹, A. Calabriso², S. Martino¹, D. Borello², M. Della Seta¹, C. Esposito¹, M. Fiorucci¹, P. Venturini²

¹ Dip. Scienze della Terra, “Sapienza” Università, Roma, Italy
² Dip. Ingegneria Meccanica ed Aerospaziale, “Sapienza” Università, Roma, Italy

Introduction. Gravitational slope instabilities can be strictly related to volcanic and hydrothermal systems as widely documented in several case studies (Reid et al., 2001, 2004; Lopez et al., 1993). Such relations are due to interactions between slope system and inner forces (Bozzano et al., 2013), produced by a renewal of the volcanic activity, magma or dikes emplacement, volcanic-related seismicity, hydrothermal pressurization (Reid et al., 2004). This close relation is strengthened by alterations effect produced by aggressive hydrothermal fluids which can compromise the mechanical properties of rocks and soils (John et al., 2008; Frolova et al., 2014; del Potro et al., 2009) often jeopardizing mechanical properties (Heap et al., 2012) and hence flank stability.

In order to evaluate the role of hydrothermal systems in conditioning slope-scale deformations, a 2D multiphysics numerical model was implemented for the Mt. Nuovo case study (Ischia Island, Southern Italy), by coupling hydrothermal and mechanical solutions.

Geological framework of Ischia Island. Ischia Island is one of the most adapt volcanic systems for studying relations between geothermal systems and development of slope-scale instabilities, because of the presence of a well developed and stable geothermal system and the occurrence during the Holocene of massive rock slope failures (Della Seta et al., 2011).

These occurrences is closely related to volcano-tectonic dynamics, mainly driven by magma emplacement and volcanic activity renewal. In a cyclical recurrence pattern (de Vita et al., 2013), slope instabilities would represent the surficial response to the general gravitational disequilibrium induced by deep deformation and caused by magmatic intrusion or pressurization.

The main volcano-tectonic event recorded in the geological succession of Ischia Island is represented by an asymmetric resurgence able to produce an uplift up to 900 m over a period of 30 ka, as testified by the present elevation above sea level of marine sediments (Tibaldi and Vezzoli, 1998).

According to Rittmann (1930) such a resurgence could have been generated by the emplacement of a shallow laccolith, or by an increase of volume and pressure in the magma chamber (Tibaldi and Vezzoli, 1998), which furthermore produced a vapor dominated hydrothermal system. The Ischia hydrothermal system is characterized by high heat flow (200-400 mW/m²) and geothermal gradients ranging between 180 and 220 °C/km (Cataldi et al., 1991; AGIP, 1987). The principal surface evidences of the presence of a vigorous hydrothermal circulation are several thermal springs and fumaroles with temperature up to 100°C, among which most vigorous localized in the western sector of the island, in the Donna Rachele fumarolic field. The geothermal system of Ischia is also characterized by important pressure fluctuations, as testified by several wells eruptions, occurred after the wells closure.

The underground fluid circulation mainly occurs within tuffs and lavas through a dense cracks network in a multilayered aquifer, controlled by the presence of fractured porous media separated by low-permeability layers and impermeable horizons (Carlino et al., 2014). According to Di Napoli et al. (2011), the hydrothermal system in the Mt. Nuovo sector is fed by rainwater with significant seawater inputs, as clearly shown by chemical and isotopic markers. The tectonic discontinuities represented by the network of sub-vertical NW-SE oriented faults which drove the resurgence, strongly controlled the hydrothermal circulation, conditioning
the lateral extension of aquifers and geothermal reservoir, locally representing preferential pathways for upwards migrations of fluids.

As documented in the literature (McKenna et al., 2004; Bachler et al., 2003), structural alignment may control the geometry of convective cells, fluid velocity, and thermal anomalies distributions in geothermal system.

The volcano-tectonic evolution of Ischia Island also affected the gravitational response of the edge of the resurgent block. Slope instability-related deposits including rock falls, slides, toppling as well as lahars and large scale debris flows and debris avalanche at Ischia has been described by many authors inland and above continental shelf all over the island (Chiocci et al., 2006; De Alteriis et al., 2009). Some of the volcanoclastic deposits are intercalated to primary volcanic, outlining a close relationship among slope instability and volcano-tectonic activity (de Vita et al., 2006).

The most important events, occurred since 3 ka, are characterized by volumes of hundreds Mm$^3$, representing the major catastrophic mass movements documented in the island since the Holocene.

Ongoing deformations still involve the edge of the resurgent block in Mt. Nuovo area over a volume of about 160-190 Mm$^3$ (Della Seta et al., 2011, 2015). This gravitational slope deformation was reported as triggered by a catastrophic volcano-tectonic event that took place around 460÷470 BC in the external portion of the edge of resurgent block (Della Seta et al., 2011 and references therein), where historical occurrence of large debris avalanche has been documented.

The spatial distribution as well as the morphological and geo-structural similarities between Mt. Nuovo slope deformations and already detached debris avalanche (Della Seta et al., 2015) strengthen the analogy between the evolution of the occurred landslide and the gravitational ongoing-deformation, leading to assume such landslides as the local evolution to collapse of a wide deforming sector.

Based on a high-resolution engineering-geological model a preliminary conceptual model of the slope-scale deformations involving the Mt. Nuovo sector was already proposed (Della Seta et al., 2015). This conceptual model highlights possible relations between hydrothermal system and ongoing slope deformation. In fact, increased pore pressures can induce transient stress field changes, so increasing the instabilities of the slope instabilities and driving fastly toward a generalized failure.

**Multiphysics 2D numerical modelling of coupled hydrothermal-slope system.** In order to investigate possible thermo-mechanical interactions between the Ischia hydrothermal system and the deep gravity-driven slope deformation a numerical modelling was designed. Starting from the conceptual model of the geothermal reservoir proposed by Carlino et al. (2014), a 2D thermo-fluid dynamic simulation was performed by the use of FEM COMSOL® code. A multilayer aquifer was defined, fixing a reservoir located at depth ranging between -150 and -800 m a.s.l.. A numerical analysis was performed, assuming a stationary, conductive and convective geothermal heat flux coupled with fluid flow in porous medium and fixing thermal boundary conditions. The 2D thermo-fluid model was validated by matching experimental thermal data obtained from deep wells (AGIP, 1987), i.e. verifying the coherence of the numerical thermal output respect with the path of measured temperature. The model of the deep hydrothermal system was combined with the engineering-geological model of the Mt. Nuovo slope, applying the output of the deep model as thermal conditioning of the slope-system thermal model. The free-convection in porous medium was solved by introducing a Bousinesq buoyancy term to the Brinkman’s momentum equation, linking resulting fluid velocity to the heat transfer equation, thus accounting for the lifting force due to thermal expansion (Hossain and Wilson 2002). In order to assess the role of structural elements in the development and characteristics of thermal convection, fault zones were implemented, by introducing linear permeable elements. The modelling results highlight a well developed steady-state convection in the shallow reservoir of Ischia western sector,
showing the clear role of tectonic elements in the ascent of fluid and confirming the hypothesis of strict relation to both the stratigraphic and structural setting (Della Seta et al., 2015). The main structural control of Mt. Nuovo gravitational slope deformations can be attributed to mayor fault lines. Preferential paths for fluid rising may have played a dual role in controlling the pore-pressure distribution and inducing the localization of hydrothermal alteration in the rock mass. The thermo-fluid dynamic model fits the temperature log-profile measured in deep wells (Fig. 1) and outputs the thermal-baric field within the Mt. Nuovo slope.

**Perspectives.** The preliminary results obtained so far encourage further numerical modelling, in order to evaluate the mechanical response of the slope system with respect to transient hydrothermal conditions and to estimate long-term effect of thermal anomalies on rock mass creep process (Chigira et al., 1992).

The here proposed numerical modelling will be enriched by specific laboratory physical and mechanical data derived by thermo-mechanical investigation on Mt. Epomeo Green Tuff.

The obtained results constitute a starting point for studies focused on the dynamics and mechanics of the gravity-induced slope evolution affecting the Mt. Nuovo area, providing the thermo-baric range which controls the evolution of the gravitational deformations.

Thermo-mechanical modelling of the Mt. Nuovo slope will be implemented to quantify the landslide hazard and infer possible paroxysmal scenarios toward general collapse.

**Acknowledgements.** This research was funded by “Sapienza” University of Rome in the frame of the project “Influence of geothermal systems and related thermal regime variations on the onset and development of large slope instabilities in the island of Ischia” (2015 - prot. C26A15FH3L - P.I. Dr. Carlo Esposito).

**References**


