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# Ischia Island (Southern Italy): a model of caldera resurgence

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Riassunto

**Isola d'Ischia: un modello di caldera risorgente**

L'isola d'Ischia, ubicata nel Golfo di Napoli, è formata da rocce vulcaniche di età compresa tra 150.000 anni e l'attuale; ultima eruzione 1301-1302. Durante questo periodo l'attività eruttiva è stata suddivisa in un ciclo antico e un ciclo recente la cui transizione è segnata dal Tufo Verde dell'Epomeo (55.000 anni), prodotto da un'eruzione ignimbritica accompagnata dal collasso calderico le cui dimensioni risultano approssimativamente di 10x7km$^2$. L'ipotesi della risorgenza della parte centrale dell'isola, condivisa da diversi autori, prevede in generale una variazione di volume di un corpo magmatico superficiale. Viene qui proposto un meccanismo di risorgenza generato dall'intrusione di un laccolite del diametro di circa 10 Km, fino a circa 1 km di profondità. E' stato utilizzato un modello di deformazione della crosta caratterizzato da due diverse fasi: bending e sollevamento a pistone del piano calderico, con un'evoluzione che prevede fratture nelle rocce di copertura e ulteriore risalita del blocco centrale lungo piani sub verticali corrispondenti al valore massimo degli sforzi di taglio. Questi rappresentano le faglie ai bordi dell'Epomeo responsabili della sismicità dell'isola (es. terremoto del 1883). Il modello proposto, vincolato dai dati geologici, geofisici e geochimici, imposti nelle condizioni al contorno nella soluzione al problema delle deformazioni del suolo, è coerente con le diverse fasi di risorgenza della caldera e dell'attività eruttiva, nonché con l'entità del sollevamento del Monte Epomeo.

Key words: *caldera resurgence, Ischia Island, laccolith.*

## INTRODUCTION

A model of caldera resurgence was applied to the Island of Ischia to explain uplift, volcanic activity and tectonics on Mt. Epomeo, as well as hystorical seismicity and slow ground movements recorded for the past 2000 years (Carlino *et alii*, 2006). The island of Ischia, situated in the western sector of the Gulf of Naples, is entirely formed by volcanic rocks deriving from eruptive centres largely destroyed or covered by subsequent activity. The oldest outcrops date back about 150,000 a BP while the most recent eruption occurred in 1301-1302 (Vezzoli, 1988; Civetta *et alii*, 1991). The central sector of the island is made up by the structure of Mt. Epomeo, whose uplift is correlated to the resurgence of the caldera, approximately 10x7 km$^2$ (Orsi *et alii*, 1991; Tibaldi & Vezzoli, 1998) formed after a large explosive eruption (55 ka BP) which deposited the Mt. Epomeo Green Tuff.

The edges of Mt. Epomeo structure are marked by NW-SE, NE-SW and also N-S systems of structurally significant faults and fractures while its uplift (about 800 m) probably occurred in fits and starts as inferred partly from the formation and age of marine terraces. The resurgence of the central part of the island was interpreted as due to an increase in magmatic pressure in the upper part of a shallow magma chamber (Carlino *et alii*., 2006 and references therein).

We assume that the source of the stress is a laccolith, with a diameter $L \approx 10$ km, rising up to 1 km depth in the centre of the island which triggered the caldera resurgence after the Mt. Epomeo Green Tuff eruption. To model the resurgence process of Ischia geological boundary conditions were imposed within the solution to the problem of the deformation of the crust, overlying the laccolith, considered an elastic plate (Fig.1).

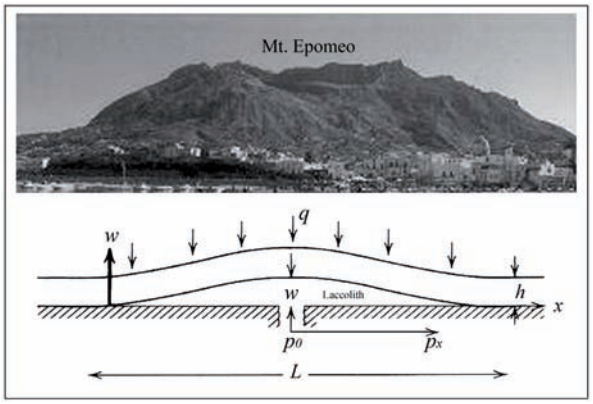


Fig. 1 – Mount Epomeo (west view) and bending (w) of an elastic plate of load q and thickness h, subjects to the thrust p0 of a laccolith of diameter L. The resurgent block is delimited by faults.

## THE BENDING-LIFTING MODEL FOR MOUNT EPOMEO RESURGENCE

The resurgence process was quantified through the bending of an elastic plate subjected to thrust from laccolith migration toward the surface (Corry, 1988; Kerr & Pollard, 1998; Turcotte & Schubert, 2001). The boundary conditions used in the quantification of the process are the thickness of the layer subjected to deformation, the distance of the faults that border the Mt.Epomeo block from the centre of maximum uplift as the expression of maximum shear strain produced by the bending process, the caldera's dimensions and the mechanical properties of the covering rocks. The shallow crustal structure of the

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island is defined using geological, deep drillings, geophysical and geochemical data; the seismicity and the temperature gradients allow us to define the rheology of the shallow crust. A brittle plate (2 km thick) is assumed to overlaps the laccolith whose behaviour is prevalently ductile. The value of geothermal gradient could indicate that the top of laccolith (at 1 km of depth) represents the cold part, with brittle behaviour, of a more extensive ductile magmatic body at depth.

The pressure $p$ of the laccolith bents upward the overburden. In a two-dimensional analysis the plate deflection ($w$) is governed by the general equation (Turcotte & Schubert, 2001):

$$D\frac{d^4w}{dx^4} = q(x) - P\frac{d^2w}{dx^2}$$

Where $q(x)$ = lithostatic load reduced by the upward pressure of the magma; $P$ = horizontal force;

$$D = \frac{Eh^3}{12(1-\nu^2)}$$

is flexural rigidity with $E$ = Young's modulus and ν = Poisson's ratio. The displacement of the plate can be determined by integrating the equation according to the boundary condition $P = 0$ . According to this solution, based on elastic plate theory the relation between the diameter ($L$) and other parameters of the laccolith should be:

$$|L| = \left(\frac{w_0 384 D}{p_0 - \rho g h}\right)^{1/4}$$

Different values of $L$ can be obtained according to: $w_0$ = 800 m, uplift of Mt. Epomeo by field data; $h$ = 2000 m; ρ = 2100 Kg m$^{-3}$; $p_0$ for different rheologies of the magma, Poisson's ratio 0.25 and Young modulus 2.5-10 GPa. The obtained laccolith diameter of 9-10 km is consistent with the geological and geophysical data.

The process of bending does not produce sufficient shear stress to fracture the rocks for the formation of a resurgent block bordered by faults, as we observed at Mt. Epomeo. Hence we invoke an evolution of the bending process producing the failure of the overburden. Two different stages are proposed: bending and faulting. The bending stage is due to sill intrusion and its thickening. As the laccolith forms, the intrusion does not lengthen due to the rapid increase in viscosity resulting from crystallization at the periphery. During this process the section of the active pushing mass decreases and consequently increases the effective pressure on the overburden till its faulting, delimiting a central block (faulting stage). When the pressure overcomes the overburden load, the block is uplifted along the faults as a "punched laccolith" according to Corry (1988). For Mt. Epomeo, we found that the distance at which magma pressure overcomes the overburden load is up to 1800 m, that corresponds to the distance of the faults bordering the block of Mt. Epomeo from its centre. This distance could represent the ray of the active section of the laccolith during the Mt. Epomeo uplift.

In order to quantify the contributions to uplift of the bending ($w_{0b}$) and punched processes ($w_{0p}$), we can set the laccolith diameter at 10 km as inferred from the diameter of the Ischia caldera and the wavelength of Bouguer gravity anomalies. The different contributions of bending and punched mechanisms are controlled by the rigidity of the overburden (the higher is Young's modulus, the lower the bending), and by the rheology of the magma. Overall, the punched mechanism provides the chief contribution to the uplift of the block. According to this mechanism, in response to pressure $p_0$, laccolith thickness increases in the zone below the block delimited by faults, which will be raised by the quantity $w_{0p}$, equal to its thickness.

Furthermore, during resurgence the block of Mt. Epomeo has undergone dismantling episodes attributed to avalanching, as testified by the study of sub-aerial and submerged deposits south of the island and from the horseshoe shape in the mountain's southern sector. These episodes appear to have produced a decrease in load $q_0$, in response to which the laccolith reached a more superficial level, with additional uplift of the block. Taking into account the eruptive history of Ischia after the Green Tuff Eruption which has three active periods 43-33,000 yr BP, 29-18,000 yr BP, 10,000 yr BP to 1302 AD, it may be reasonably hypothesized that the uplift of Mt. Epomeo occurred at steps during the time intervals of quiescence, i.e. 55-43,000, 33-29,000, 18-10,000 yr BP. In this case the block's resurgence rate was 3.3 cm a$^{-1}$. Along the faults of the northern side of Mt.Epomeo seismic energy was released during historical times till to 1883. Since that time in the island a seismic silence was observed, while a general subsidence occurred. We hypothesized that the upheaval is accompanied by moderate to intense seismicity, on the contrary the subsidence develops without seismicity.

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