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Sources of ground movement at Vesuvius before the AD 79 eruption: Evidence from contemporary accounts and archaeological studies

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ABSTRACT

Historical sources have recorded earthquake shocks, their effects and difficulties that local inhabitants experienced before the AD 79 Pompeii eruption. Archaeological studies pointed out the effects of such seismicity, and have also evidenced that several water crises were occurring at Pompeii in that period. Indeed numerous sources show that, at the time of eruption, and probably some time before, the civic aqueduct, having ceased to be supplied by the regional one, was out of order and that a new one was being built. Since Roman aqueducts were usually built with a recommended minimum mean slope of 20 cm/km and Pompeii's aqueduct sloped from the nearby Apennines toward the town, this slope could have been easily cancelled by uplift that occurred in the area even if this was only moderate.

For the crustal deformations a volcanic origin is proposed and a point source model is used to explain the observations. Simple analysis of the available data suggests that the ground deformations were caused by a <2 km^3 volumetric change at a depth of ~8 km that happened over the course of several decades.

1. Introduction

The Somma–Vesuvius volcano formed mostly during the last 25 ka (Andronico et al., 1995) and has been characterized either by periods of semipersistent activity or by long periods of quiescence, interrupted by Plinian or subplinian eruptions.

The volcano produced at least four Plinian eruptions before AD 79 (at 18, 16, 8 and 4 ka B.P.) and many smaller-scale subplinian eruptions (Rolandi et al., 1998; Andronico and Cioni, 2002; Santacroce and Sbrana, 2003). By means of reports and geological investigations it has been ascertained that from the early centuries of the first millennium, two subplinian eruptions at least (AD 472 and 1631), and several significant explosive events in the *III* (AD 203) and *VI* (AD 512) centuries as well as in AD 685 and AD 1036 occurred (Figliuolo and Marturano, 1997, 1998; Santacroce and Sbrana, 2003). From 1631 to 1944 the volcano produced eighteen eruptive periods of small and medium-sized eruptions from both summit and side vents (Arrighi et al., 2001; Santacroce and Sbrana, 2003). After the 1944 eruption Mt. Vesuvius has been quiescent.

The AD 79 eruption has been widely studied in the last forty years and several interpretations of its dynamics have been proposed (e.g. Lirer et al., 1973; Sigurdsson et al., 1985; Carey and Sigurdsson, 1987; Cioni et al., 1990, 1992, 1996; Yokoyama and Marturano, 1997; Mastrolorenzo et al., 2001; Luongo et al., 2003; Gurioli et al., 2005; Rolandi et al., 2007). The eruption was characterized by phreatomagmatic explosions and by two styles of activity: a first Plinian phase, during which widespread fallout deposits were emplaced, followed by a second phase characterized by numerous pyroclastic flows. About 4 km^3 of material was discharged and the surrounding towns of Pompeii, Herculaneum, Oplonti and Stabie were destroyed (Sigurdsson et al., 1985).

Several earthquakes preceded the eruption. The strongest of them that occurred in AD 62, and that affected the city of Pompeii severely, is considered strictly related to the AD 79 event (Marturano and Rinaldis, 1995; Luongo et al., 1995; Cubellis and Marturano, 2002; Cubellis et al., 2007).

In the last years of the Roman Empire and Medieval times the available sources recorded no significant seismic activity in the Vesuvian area in spite of the occurrence of some large eruptions (Figliuolo and Marturano, 1997, 1998).

There is evidence for seismic activity since the eruption of the 1631 up to recent times, but it was generally of low to moderate energy and related to eruptive activity (Marturano and Scaramella, 1995, 1997; Cubellis and Marturano, 2002; Principe et al., 2004; Bertagnini et al., 2006).

Since 1944, seismicity at Vesuvius has been marked by events with a frequency of a few hundred per year with some episodes of higher seismicity and higher magnitudes concentrated in the summit caldera at a depth of less than 6 km below sea level (Vilardo et al., 1996; Bianco et al., 1999; Capuano et al., 1999; Zollo et al., 2002; Cubellis and Marturano, 2002; Del Pezzo et al., 2004; De Natale et al., 2004, 2006).

In spite of the rich volcanologic and seismic records, ground deformations have been rarely associated to Vesuvian eruptions. Sigurdsson et al. (1985) evidenced ground subsidence at Herculaneum,

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probably due to deflation as a consequence of the AD 79 eruption, and Palmieri et al. (1862) associated ground deformations to the lateral eruption of 1861 that opened vents at low altitude.

The collection of systematic ground deformation data for Mt. Vesuvius started in the second half of 1970 with the installation of a planimetric network along its flanks (Bonasia and Pingue, 1981; Berrino et al., 1993; Tammaro et al., 2007). Since that time, the volcano has shown no significant dynamics. Indeed, high precision levellings, tiltmeters, tide-gauges along the coast, GPS measurements and InSAR images (Lanari et al., 2002; Pingue et al., 2004, 2005; Tammaro et al., 2006) indicate two well-defined zones of subsidence: in the upper part of the volcano and in a narrow strip on the plain around it.

Knowledge of past precursor patterns, specific in each volcanic system, is crucial for high-risk volcanoes (e.g. McNutt et al., 2000; Sparks, 2003).

For Vesuvius, the absence of significant recent and past ground movements linked to internal dynamical processes makes unusual thing to relate the evolution of the surface displacement to the variation in pressure in a shallow reservoir. Furthermore, numerical modelling found maximum vertical displacements to be only a few centimetres (Russo et al., 1997); therefore, evidences from past ground deformations associated to magmatic sources cannot be left out.

Archaeological proofs suggest that a long period of intense ground deformation preceded the AD 79 eruption.

This paper aims mainly to ascertain whether the ground deformations recorded by archaeological studies can be reasonably modelled by volcanic sources and aims to comprehend whether the processes involved are consistent with the seismicity recorded by historical sources.

2. Geostructural setting

The Somma–Vesuvius complex (Fig. 1) lies at the southern end of the Campanian plain, which is bordered by Mesozoic platform carbonates forming the basement dissected by a Plio-Pleistocene NE–SW and NW–SE trending regional fault system related to the opening of the Tyrrhenian basin (Patacca and Scandone, 1989). The whole southern Apennines area is characterized by NE–SW oriented extension (Montone et al., 2004).

The buried geometry of the carbonate basement under Somma–Vesuvius is delineated by a sharp increase in P- and S-wave velocities around 2 km b.s.l. (Zollo et al., 1998) according to data from deep drilling on the volcano's southern slope (Principe et al., 1987). Calibrated Bouguer anomalies modelled the basement around the volcano confirming the slight west dipping (Bruno et al., 1998). Volcanic and sedimentary sequences cover the carbonate basement that overlies the crystalline basement at a depth of 12 km (Berrino et al., 1998).

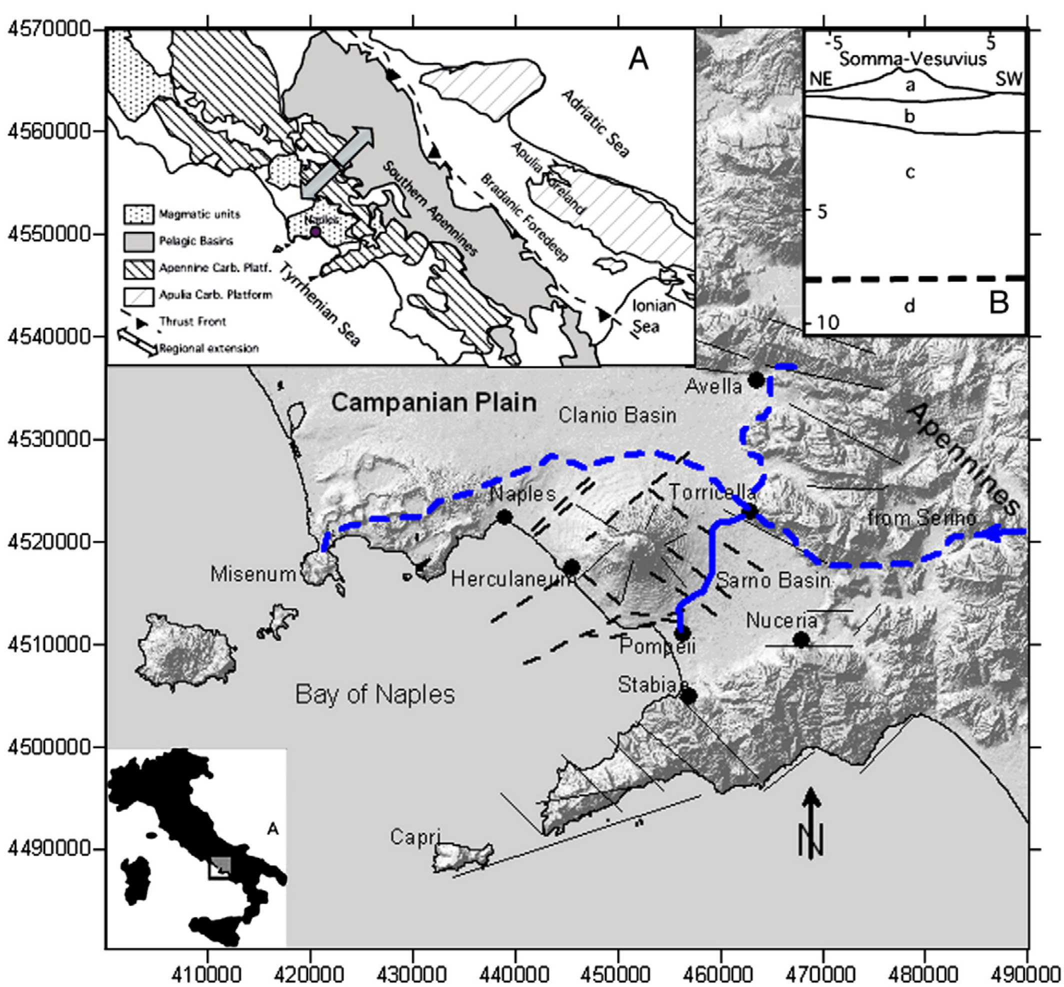

Fig. 1. Main tectonic structures of Mt. Vesuvius and the Campanian Plain. Continuous lines: topographic lineaments and faults (by: Milia and Torrente, 1999; Acocella and Funiciello, 2006; Cubellis et al., 2007). Dashed lines and points: faults and fractures of the shallow basement from geophysical surveys (by: Maino et al., 1964; Bruno et al., 1998; Ventura and Vilardo, 1999; Cubellis et al., 2001). Bold lines (aqueducts): Serino–Misenum (dashed); Avella–Torricella (dashed); Torricella–Pompeii (continuous). Inserts: A, geologic sketch map of Southern Italy; B, schematic section crossing Somma–Vesuvius (see text for bibliography): a) volcanic deposits and lavas; b) interbedded lavas, volcanoclastic, marine, and fluvial sedimentary rocks of Pleistocene age; c) Mesozoic carbonate basement; d) low velocity layer.