

Active deformation in Naples Bay evidenced by joined high-resolution marine geophysics and InSAR processing

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An integrated marine geophysics and satellite remote sensing study of Naples Bay (Italy) has been carried out to evaluate the presence, magnitude, areal extent and activity of the Naples Active Deformation Line (NADEL), a structural bend affecting the post Last Glacial Maximum (LGM) sedimentary sequences. Sparker high-resolution mono-channel profiles and multibeam swath bathymetric data were acquired during the SAFE_2014 research cruise, carried out on board of the Urania R/V of CNR on August 2014. The marine geophysical study was integrated with the ground deformation field of the emerged sectors of the study area (Sorrento Peninsula and Campi Flegrei), derived by Synthetic Aperture Radar interferometry (InSAR) data, referred to the 1993-2000 and 2003-2010 time periods. The InSAR data obtained from the ERS, RADARSAT and ENVISAT images were processed with the method of Permanent Scatterers (PS). Marine geophysical data provide evidence of morphological and stratigraphic features extending for about 18 km along a N130E strike. The NADEL deformation bend divides a NE offshore area, characterized by a flat morphology (slope < 1°, on average) from a SW sector, where the slope at >180 m below the sea level is, on average, 1.5°. In the area located SW of NADEL, the slopes are morphologically characterized by the presence of the uppermost active branches of the Magnaghi canyon, which are bounded upward by the presence of the NADEL pattern. Thus, we suppose that the emplacement of the Magnaghi branches and NADEL are linked. InSAR data show that a similar deformation pattern can be detected also inland, in the distal sectors located NW and SE from the NADEL edges. The NADEL segments also affect the distal SW sector of the Campi Flegrei active caldera and the carbonate units cropping out in the Sorrento Peninsula, thus extending in length for more than 40 km.

I. INTRODUCTION AND GEOLOGY

Despite the growing interest for both the exploration of marine sectors and the structural mapping of fractures potentially related to the emplacement of volcanism offshore the Campanian Plain and Napoli Bay, a deep knowledge of the marine active deformation is still lacking. Naples Bay includes active volcanic areas characterized by the presence of three major volcanic complexes, i.e. Ischia, Campi Flegrei (also including

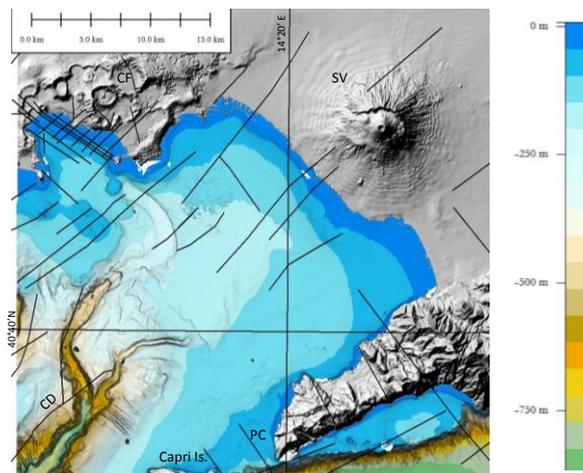


Fig. 1. Location map and morphobathymetry of the study area. Faults (lines) after [5, 6, 7, 8, 9 and 10].
CF=Campi Flegrei, SV=Somma-Vesuvius,
CD=Canyon Dohrn, PC=Punta Campanella.

Procida) and Somma-Vesuvius (Fig. 1). Their activity yielded three main catastrophic eruptions, i.e. Green Tuff, 55 ka [1]; Campanian Ignimbrite, 39 ka [2]; Neapolitan

Yellow Tuff, 14 ka [3], whose products covered most of the region. In addition, plinian eruptions occurred in historical times [4]. The Bay of Naples is a Middle Pleistocene half-graben filled by mixed siliciclastic-volcaniclastic depositional sequences arranged in

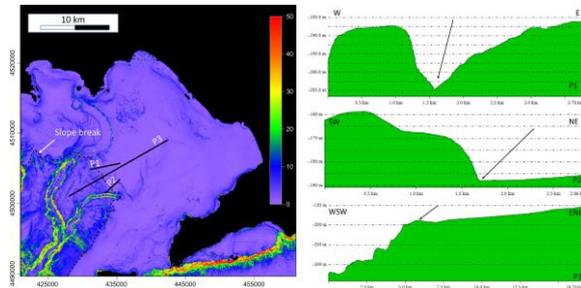


Fig.2. DTM extracted slope map and profiles.

aggradational–progradational stacking patterns. Several authors pointed out those eruptive centers emplaced on NE–SW and subordinately NW–SE deep system of fractures [5]. In Naples Bay, recent faults were mapped by using geophysical data [6, 7, 8, 9, 10]. The volcanic areas is mainly affected by NE–SW and NW–SE striking fractures and faults with subordinate (and older) N–S and E–W trending structures [11]. These preferential pathways of magma and hydrothermal fluids were also recognized in the basal architecture of Ischia, Campi Flegrei, and Somma–Vesuvius [12, 13, 14]. Deformations related to both volcano–tectonic and regional–tectonic stress fields were recorded from historical, geomorphological, geophysical and archaeological sources [15, 16, 17]. Several major faults connecting marine morpho–structural features with the main volcanic complexes were mapped in the last 20 years. In detail, the recent NW–SE and NE–SW system in the Naples shelf [14], the NE–SW trending system controlling the bradyseism of Campi Flegrei and the complex set of faults of Mount Epomeo, which is the main volcanic center of Ischia. The whole Naples Bay is crossed by three main, NE–SW striking faults, i.e. the northern slope of Sorrento Peninsula, the Magnaghi Sebeto fault and the Vesuvian Fault. These faults are likely the conjugate fault system resulting by NW–SE faults related to the opening of the Campanian Graben [18]. Overall, the knowledge of the actual deformation pattern is a fundamental task for the hazard evaluation. The information of the offshore active deformation field is poorly known because of intrinsic difficulties and high costs required for high–resolution investigations. Despite the growing interest for both the exploration of marine sectors and the structural mapping of fractures potentially related to the emplacement of volcanism in the area, a deep knowledge of marine active deformation in the area is still lacking.

II. DATA AND METHOD

Multibeam swath bathymetry and Digital Terrain Model

The bathymetric survey of Naples Bay (Fig. 1) was carried out by IAMC–CNR in the frame of the SAFE 2014 oceanographic survey on board the Urania research vessel. We used a Simrad EM 710 multibeam equipment (Kongsberg©inc.), characterized by a 70–100 KHz acoustic source frequency, 400 soundings per swath and 140° of pulse width, and allow data acquisition until 1200 m depth (2000 m in cold waters with low salinity). The MBES measurements were geo–referenced in real–time by using a differential global positioning system and a motion sensor. Sound velocity profiles (SVP) were measured each 6–8 h. SVP values were normally applied in real–time during surveys. MBES data processing was carried out with PDS2000 software following the International Hydrographic Organization standards. Data processing was chiefly aimed at removal of navigation errors, noise reduction, i.e. de–spiking, removal of poor quality beams, and tidal and sound velocity corrections. Then, depth measurements are spatially re–organized in a regular matrix to obtain a Digital Terrain Model (DTM, Fig.1). The spatial resolution of the DTM depends on several parameters, including: a) water–depth range of the survey area, b) number of beams, c) SVP accuracy, d) instrumental frequency and positioning system that was used. Vertical resolution mostly depends on the instrumental frequency while the horizontal resolution depends mainly on the “footprint”, (i.e. on the number of beams per square unit as a function of water–depth). The final processed data allowed to realize a grid with a 5 m cell–size and a slope map (Fig. 2). Terrestrial data are derived from the official topographic grid of the Italian Military Institute for Geography (IIGM), which has a 20 m spaced grid.

Mono–channel reflection seismic profiles

High–resolution seismic reflection profiles was recorded along the continental shelf and the upper slope of the Naples Bay on board the R/V Urania (CNR). The acoustic source used during seismic prospecting was a 1 kJ Sparker power supply with a multi–tips Sparker array, which lacks ringing and has a base frequency of around 800 Hz, fired at a time interval of 1.5 s. Data were recorded using a single–channel streamer with an active recording of 2.8 m, containing seven high–resolution hydrophones, for 1.3 s. two way time (t.w.t.) at a 10 kHz (0.1 ms) sampling rate. Positioning was controlled by a Differential Global Positioning System. Data processing was performed using the Geo–Suite AllWorks© software package, running the following

mathematical operators: spherical divergence correction, de-ghosting, migration, band-pass (400-3000 Hz) filter, swell filter, trace mixing, time variant gain and mute of water column. Signal penetration was found to exceed 500 ms t.w.t. The vertical resolution is ~2.5 m near the seafloor.

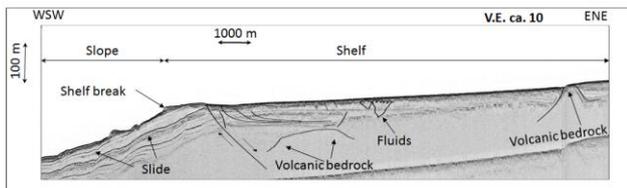


Fig. 3. Sparker profile on NADEL. Navigation is P3 in Fig. 2

SAR Interferometry

Synthetic Aperture Radar Interferometry (InSAR) is currently used for measuring slow ground-surface deformation movements occurred from early '90's to now. InSAR technique provides very accurate, unidimensional, sub-centimetric measurements of slow ground movements along the line of sight (LOS), referred as the straight line between radar sensor and the ground target [19, 20].

In Campania region territory, an overall perspective on the spatial distribution of ground deformation due to dynamic processes, including volcanism, tectonics and subsidence [21, 22, 23] can be assisted by space-borne InSAR techniques, exploiting the C-band sensors onboard ERS (from 1992 to 2001), ENVISAT (from 2002 to 2010) and RADARSAT (from 2003 to present) satellites.

Several interferometric techniques have been proposed for the extraction of ground deformation velocity from SAR data, such as Permanent Scatterers (PS-InSAR) [24]. The Persistent Scatterers (PS) technique requires a master scene and a stable reference point, assumed motionless, to which the zero in the time series and the relative measurements of deformation are respectively referred [24].

The PS material used in this study is represented by four PS datasets selected respectively from: a) ERS-1/2 ascending orbit, b) ERS-1/2 descending orbit, c) RADARSAT ascending orbit, d) RADARSAT-descending orbit, obtained by the TELLUS Project [25]. In this paper we used the RADARSAT Ascending orbit dataset, which includes more than 113.000 persistent scatterers identified within the study area that extends about 800 km². The annual average velocity values ranges from + 7.16 to - 15.34 mm/yr. Compared to the ERS images, RADARSAT images provide significantly

higher point density and a high spatial resolution of ground deformation, but the identified points are in equivalent number when comparing ascending and descending orbits. The PS dataset has been referenced to WGS-84 Datum UTM Projection, 33N Zone, geometrically checked and spatially processed using GIS software.

III. RESULTS AND DISCUSSION

Bathymetric and seismic evidences

Shelf morphology is the result of a complex interplay between short and long term processes, like sedimentary processes, currents, tide, rate of sediment supply, transgression and regression of the sea-level, tectonics, etc. [26]. The shelf break, in particular, is defined by a change in the seafloor slope (Fig. 2) marking the boundary between the flat continental shelf and the steeper continental slope. In Naples Bay, the shelf break is deeper than the expected (located at about -180 m on average, Fig. 2). The seafloor rise extends for about 10 km and strikes N135°E. This deformation is not typical of the shelf-break, which is normally made up by a gradient in slope with increasing slope values. After the seafloor rise and toward the deeper waters (i.e., south-westward) the slope starts, and it is mainly occupied by the apical part of the Dohrn canyon branches. Due to normal re-disposal of sediments, current flows and sediment attraction made up by the contiguous Dohrn Canyon, any morphological obstacle located in proximity of the shelf-break should be removed in a short (geo-morphological) time span. Thus, the observed relative high of the seafloor is to be considered as the effect of an active deformation line (hereafter NADEL) built by geologic structures and characterized by a recent or a present activity. In addition, its northern prosecution shows the evidence of a linear trend bounding the Penta Palummo Bank, an almost rectangular edifice measuring 3.6 x 2 km located on the southern boundary of Campi Flegrei. The presence of a volcanic body on its summit, that lies on the NE side and strikes N 130°E for about 1.4 km up to -50 m b.s.l., presumably indicates a structural control for the emplacement of the bank itself, that should represent the northward prolongation of NADEL (Fig. 1, 2). This hypothesis is confirmed by the acquired sparker mono-channel profiles (Fig. 3). NADEL consists in a N130°E, striking fault. The sparker section also shows that all the layers located in the slope area are likely controlled by gravitational instability, while the shelf is dominated by the morpho-structural infill of marine sediments intercalated to pyroclastic flows (presumably Yellow Tuff and Campanian Ignimbrite), volcanic bedrock items and rising up of fluids (Fig. 3) like those observed in other sectors of Naples Bay [10, 27].

Ground deformation trends in emerged area

The deformation patterns of study area obtained by PS-InSAR processing is showed in Fig. 4, which is referred to RADARSAT Ascending orbit dataset.

The velocity value distribution (Fig. 4) shows a regional pattern characterized during 2003-2007 years by widespread negative values (Naples town, Vesuvius,

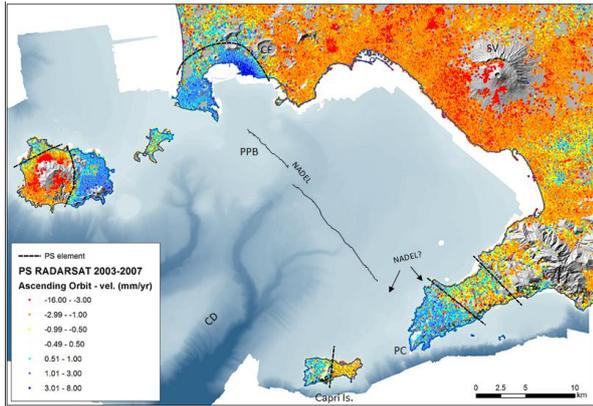


Figure 4 - Map view of 2003–2007 range-change rate measurements of PS derived by RADARSAT ascending orbit and possible location of NADEL (black line). The underlying image is a shaded relief from a 20 m pixel Digital Terrain Model (on land) and from a 5 m pixel DTM of the area. CF=Campi Flegrei, SV=Somma-Vesuvius, CD=Canyon Dohrn, PC=Punta Campanella, PPB=Penta Palummo Bank.

Sarno river plain and Lattari Mts. sectors), and localized trends of positive values in Campi Flegrei, western sector of Ischia island, eastern sector of Sorrento Peninsula and easternmost sector of Capri island.

In the Ischia and Campi Flegrei sectors, we observe the highest positive values (> 3 mm/year), which identify areas affected by significant uplift, related to active volcano-tectonic processes in Monte Epomeo and Campi Flegrei caldera [21, 22, 23].

Along the southern border of the Naples Gulf (Sorrento Peninsula), where NW-SE striking normal faults are present in the carbonate tectonic units [21], we can observe clear differential movements. A linear element (Fig. 4) splits up a subsidence area (Sorrento graben) by an uplift sector (Punta Campanella area). This element corresponds to the active deformation line (NADEL), recognized on the seafloor.

III. CONCLUDING REMARKS

An active, N130°E tectonic lineament (NADEL) was detected and mapped in the marine sector of Naples Bay by integrating multibeam swath bathymetry and sparker seismic profiles. NADEL runs across both volcanic

relative high from the seafloor (Penta Palummo Bank) and sedimentary features. In addition, NADEL shapes an elongated anticline structure in the central sector of the Bay. Overall, the presence of NADEL separates the outer shelf from the slope, thus morphologically constraining the sediment attraction made up by the uppermost section of the Dohrn Canyon. This lineation was also recognized inland on the Sorrento Peninsula, where differential movements have been detected thanks to DInSAR measurements.

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