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Geodynamics of the Calabrian Arc area (Italy) inferred from a dense GNSS network observations

Giuseppe Casula *

Istituto Nazionale di Geofisica e Vulcanologia (INGV), Sezione di Bologna, Via Donato Creti 12, I-40128, Bologna, Italy

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ABSTRACT

The tectonics and geodynamics of the Calabria region are presented in this study. These are inferred by precise computation of Global Navigation Satellite Systems (GNSS) permanent station velocities in a stable Eurasian reference framework. This allowed computation of the coordinates, variance and covariance matrixes, and horizontal and vertical velocities of the 36 permanent sites analyzed, together with the strain rates, and using different techniques. Interesting geodynamic phenomena are presented, including compressional, and deformational fields in the Tyrrhenian coastal sites of Calabria, extensional trends of the Ionian coastal sites, and sliding movement of the Crotone Basin. Conversely, on the northern Tyrrhenian side of the network near the Cilento Park area, the usual extensional tectonic perpendicular to the Apennine chain is observed. The large-scale pattern of the GNSS height velocities is shown, which is characterized by general interesting geodynamic vertical effects that appear to be due to geophysical movement and anthropic activity. Finally, the strain-rate fields computed through three different techniques are compared.

1. Introduction

At present, several institutions in Italy maintain Global Navigation Satellite Systems (GNSS) networks, to furnish potential users with precise positioning of sites in the field by simply operating a GNSS receiver with an antenna. For the Italian peninsula, there are hundreds of permanent GNSS sites that are operated daily by different institutions, such as government bodies, local and regional administrations, and private companies. In general, receiver-independent exchange format (RINEX), 30-s-rate GNSS data are made freely available to users through ftp or http servers. Some regional government bodies, including Liguria, Campania, Calabria,

* Tel.: +39 051 4151415; fax: +39 051 4151499.
E-mail address: giuseppe.casula@ingv.it.
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Emilia Romagna, and Piemonte, provides users with the highest rate data (≤1 s), and transmit ambiguity corrections for real-time kinematic positioning.

These facilities can be valuable tools for geodynamical studies of high risk seismic areas [1] like the Calabria region in Italy. The Calabrian region is composed by Paleozoic aged crystalline rocks which gave rise to the Sila, Serre and Aspromonte massifs. Three groups of archaic rocks can be classified as follows: granitic, gneiss and mica-schists.

The group of the granitic rocks has developed particular along the Ionian coast giving rise to the zone of the Sila and Serre [2]. The group of gneiss rocks crop out mainly along the west part of the Sila massif, in the coastal chain coming from Paola to Cosenza, along the Maida and Chiaravalle plateaus to reach finally the Aspromonte massif together with the group of mica-schist, which can be defined as typical Aspromonte rock highly altered by metamorphic phenomena either in the aspect and structure.

The Mesozoic terrains of the secondary age constitutes practically one third of the southern mountains of Calabria region and are present in different shapes and aspects starting from Lagonegro village to Castrovillari and from Pazzano village to arrive at the Ionian sea.

Terrains of the tertiary age (Cenozoic) indeed, composed mainly by sedimentary rocks like clays and sandstone, have been originated by metamorphic strong phenomena and can be observed near Reggio Calabria Province, and in the mountains of Mosorrofa, Terreti and Ortì that reaches heights ranging from 700 to 1200 m above sea level, and are mainly composed by marine sediments [2].

The Calabria region is one of the highest seismic risk area of the world, in fact it is collocated along the zone of contact between Eurasia and Africa plates. For this reason it is practically compressed inside the big jaw constituted by these two plates. The earth crust of Calabria region is for this reason broken in big active normal seismogenetic faults dipping 10–15 km and long several km, and delineating graben styled structures.

The fault system of the Calabria region is represented in Fig. 1 with red lines, together with the earthquakes that historically occurred in this area with magnitude ≥6 which are represented with yellows dots. In particular, we can enumerate the following catastrophic events: the Valle of Crati earthquake of 1183, the Messina strait earthquake of 1908, the seismic sequence of the southern Calabria of 1783, the earthquakes of central Calabria occurred respectively in 1638 and 1905, the Cosentino area earthquakes of 1835, 1854, and 1870 [3,4].

This high magnitude seismicity makes the Calabria one of the Italian region more exposed to natural risks (quakes, tsunamis, and landslides), moreover it caused in the past more than 200.000 human casualties (1908) [5], high costs and damages.

From the geodynamical point of view the dominant mode of crustal deformation of the Calabrian area is represented by normal faulting with ESE-WNW extensional trend originated during the Middle Pleistocene.

A sliding movement of the Crotone Basin is present moving toward east, conversely along the Apenninic chain an extensional trend can be observed crossing the chain from west to east [6].

The area is then characterized by the slab of the Ionian sea that is submerged under the Arc in the ESE-WNW direction and is characterized by a subduction zone being located on the top of a narrow active Wadati-Benioff zone [6]. The tectonics that originated this area are in some way connected with the phenomena that originated the volcanic arc of the Aeolian Islands that is due to movement of the Earth's crust as a result of plate tectonics. The African continental shelf is in constant movement towards Europe. The resulting collision has created the volcanic arc of the Aeolian Islands.

More than 50% of the earthquakes that occurred in the Italian peninsula gave rise in Calabria along the active faults represented in red in Fig. 1. Many of these structures can potentially produce earthquakes of Magnitudes ≥7 (1638, 1783, 1905, 1908) [2–4].

As a supporting tool for the considerations written above, this study have gathered together daily GNSS RINEX 30-s daily data from the three public companies of RING (http://www.ring.gm) [7], EUREF (http://www.epncb.oma.be), and UNICAL, which are combined with the freely available ITALPOS (http://it.smartnet-eu.com)) Leica Geosystems data from this Italian private company network. These data are used to compute a dense and very accurate GNSS network of daily solutions over a 6-year time span, from the beginning of January 2008, to the end of December 2013 (see Table 1) [1,7].

After robust data archiving using a suitably prepared Unix shell and the Fortran90 and C utilities, these data are processed using a distributed sessions approach [8–10]. They are then combined with other institution solutions and compensated, to obtain the station time series and velocities. Finally, different algorithms are applied to compute the pattern of the continuous strain-rate of the Calabrian area under study. Indications on the tectonics and geodynamics of this complex and interesting high-seismic-risk area are also provided.

2. Geodynamic setting of the Calabrian Arc

The Calabrian Arc is defined as the mountain chain belt lying under the eastern part of the Tyrrhenian Sea. It has a curved shape due to the compression acting between the Sicilian Maghrebides and the southern Apennines, the remote force for which is represented by the active north-eastern pushing of the African plate against the Eurasia plate. A peculiarity of this area is that the central part of the arc is dominated by the polymorphic Calabrian–Peloritanian mountain chain. This was generated by retro-arc tectonics that originated through the subduction of the Ionian Sea lithosphere under the continental crust of the Ionian area. In other words, the Calabro–Peloritanian domain is located on the upper part of a very narrow slab that is characterized by deep seismicity, which has been clearly delineated by the modern inversion of seismic tomography data [11,12, and references therein].

In this complex geodynamic context, there are two interesting aspects that need to be underlined, also when looking at the GNSS network solution in the Calabria region:

(a) Despite the very slow modern-day plate convergence rates observed by GNSS, subduction might still be active in the Calabrian Arc, whereby the subduction rate will