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# A ~125° post-early Serravallian counterclockwise rotation of the Gorgoglione Formation (Southern Apennines, Italy): New constraints for the formation of the Calabrian Arc

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ABSTRACT

The Southern Apennines, Calabro-Peloritane block, and Sicilian Maghrebides form a ~700 km long orogenic bend, known as Calabrian Arc (Cifelli et al., 2007). The bending of this orogenic system was realized progressively through opposite-sense rotation of the two limbs, counterclockwise (CCW) in the Southern Apennines and clockwise (CW) in the Sicilian Maghrebides, synchronous to the Miocene-to-Present opening of the Tyrrhenian Sea. Despite the wealth of paleomagnetic data from the Southern Apennines, the main Miocene rotational phase still remains poorly constrained in time and, more importantly, data from the most internal paleogeographic domains of the belt are completely lacking.

The Gorgoglione Formation, a middle Miocene piggy-back deposit of the Southern Apennines, unconformably resting over the internal Sicilide Unit, offers the unique opportunity to document the deformation pattern of the most internal units, and reconstruct the incipient tectonic phases leading to the formation of the Calabrian Arc. New paleomagnetic and biostratigraphic data from the Gorgoglione Fm. reveal a post-early Serravallian ~125° CCW rotation with respect to stable Africa. Such a large rotation, affecting the Gorgoglione Fm. (and consequently the underneath allochthonous Sicilide nappe) exceeds by ~45° the maximum mean CCW rotation previously reported for the Southern Apennines. We propose that the additional ~45° CCW rotation measured in the Sicilide Unit is the result of an earlier, late Miocene phase of deformation related to the onset of the Tyrrhenian Sea opening and affecting the most internal paleogeographic domains of the Southern Apennines. Our reconstructed tectonic scenario confirms and emphasizes the central role of the Ionian slab in the geodynamic evolution of the central Mediterranean.



## 1. Introduction

The Cenozoic tectonic evolution of the central Mediterranean, and in particular the bending of the Alpine–Apenninic belt into an S-shaped orogen, was closely influenced by the geodynamic processes associated to the narrow Ionian oceanic seaway intervening between the European and African plates (Faccenna et al., 1997, 2001, 2007; Malinverno and Ryan, 1986; Rosenbaum et al., 2002). Slab roll-back of the Ionian lithosphere triggered, since the late Eocene, back-arc extension and progressive opening of the Liguro–Provençal basin and Tyrrhenian Sea (Faccenna et al., 1997; Kastens et al., 1988; Malinverno and Ryan, 1986). Subduction of the Ionian slab is testified by the Benioff plane deepening down to 300 km beneath the southern Tyrrhenian Sea (Fig. 1) (Chiarabba et al., 2008; Neri et al., 2009). The evolution of the Tyrrhenian Sea started in the early Serravallian when the locus of the back-arc extension jumped from the eastern to the western margin of Sardinia, isolating an independent continental block (Calabro-Peloritane block (CPB), Fig. 1) (Faccenna et al., 1997; Mattei et al., 2002). During middle–late Miocene times the CPB detached completely from Sardinia and migrated ~ESE-ward following the backward-retreat of the Ionian slab (Duermeijer et al., 1998; Faccenna et al., 1997, 2001; Kastens et al., 1988; Malinverno and Ryan, 1986; Patacca and Scandone, 1989; Patacca et al., 1990). This process was accompanied by opposite-sense vertical axis rotations in the adjacent orogenic domains, counterclockwise (CCW) in the Southern Apennines, and clockwise (CW) in the Sicilian Maghrebides (see Cifelli et al., 2007 for a comprehensive review). This protracted process eventually resulted into a ~700 km-long salient, namely the Calabrian Arc (Cifelli et al., 2007, 2008; Mattei et al., 2007) currently encircling the southern Tyrrhenian Sea. The regional rotation pattern of the Calabrian Arc is shown in Fig. 1.

The paleomagnetic data from the Southern Apennines in the northern limb of the Calabrian Arc, revealed an overall post-middle

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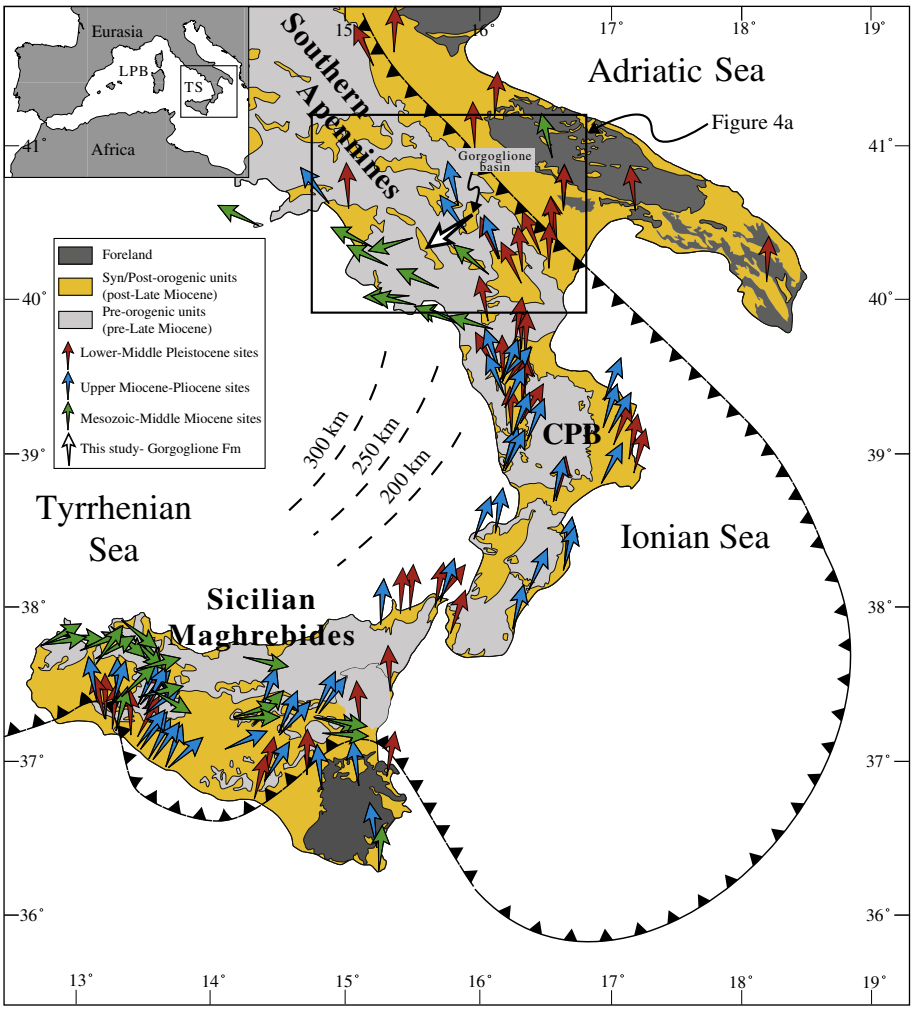


**Fig. 1.** Geological map of the Calabrian Arc showing the estimated tectonic rotations (colored arrows) with respect to stable Africa computed by Cifelli et al. (2007). Dotted lines represent isolines of the top of the Ionian slab (after Chiarabba et al., 2008). CPB, Calabro-Peloritane block; LPB, Liguro–Provençal basin; TS, Tyrrhenian Sea.

Miocene ~80° CCW rotation, with local maximum values as large as 106° (Gattacceca and Speranza, 2002). Part of this rotation (~20°) occurred in the early Pleistocene, when the compressive fronts shifted eastward affecting more external domains (Mattei et al., 2004; Sagnotti, 1992; Scheepers, 1994; Scheepers and Langereis, 1994; Scheepers et al., 1993). The southern limb of the arc (the Sicilian Maghrebides) underwent an overall post-middle Miocene ~100° CW rotations (with local 134° CW rotation documented from the most internal paleogeographic domains). Here the rotation magnitude decreases progressively from the internal towards the external domains of the belt (Butler et al., 1992; Channell et al., 1980, 1990; Oldow et al., 1990; Speranza et al., 1999, 2003). Conversely, in the Southern Apennines it is not possible to assess a similar pattern on the basis of the available data. The main rotational phase ended in the middle Pleistocene in both the Southern Apennines and Sicilian Maghrebides.

Despite the extensive paleomagnetic dataset available for the Southern Apennines, the onset of the main rotational phase is still poorly constrained in time due to the limited number of sites (only two) from Miocene rocks (Gattacceca and Speranza, 2002). Furthermore, the rotational history of the most internal paleogeographic domains, currently resting at the top of the orogenic pile, is totally unknown. Relying on the available dataset, the Calabrian Arc displays a not truly symmetrical bending (Cifelli et al., 2008), with the southern limb showing larger rotations than the northern one. Furthermore, some authors invoke the Europe-Africa convergence as the only driving force for the bending of the Calabrian Arc (Johnston and Mazzoli, 2009). Accordingly, a number of moot points are still present: What is the timing and magnitude of the rotations related to the earliest stage of deformation in the Southern Apennines? Was the bending of the Calabrian Arc symmetrical or asymmetrical? Is the Ionian slab the only driving mechanism for the bending of the Calabrian Arc, or the Europe–Africa convergence contributes to the regional deformation as well?

We tried to address these questions carrying out an integrated paleomagnetic and biostratigraphic study of the Gorgoglione Fm., a middle Miocene piggy-back deposit of the Southern Apennines (Boenzi and Ciaranfi, 1970; Boiano, 1993, 1997; Cocco et al., 1972; Critelli and Le Pera, 1994; Critelli and Loiacono, 1988; Patacca et al., 1990; Pescatore et al., 1980, 1999) resting in unconformable contact above a unit (i.e., the Varicolored Clays, interpreted as part of the Sicilide Unit) of internal paleogeographic provenance (Cinque et al., 1993; Critelli, 1999; Lentini et al., 2002; Monaco and Tortorici, 1995; Patacca and Scandone, 2007). Because of these features the Gorgoglione Fm. offers a unique chance to investigate on the rotation history of the most internal paleogeographic domains of the Southern Apennines, and reconstruct in more detail its geodynamic evolution in the framework of the Calabrian Arc formation.

## 2. Geological setting

The Southern Apennines are a fold-and-thrust belt composed of both autochthonous and allochthonous marine sedimentary units