



# The Timpa Delle Murge Ophiolitic Sequence (Southern Italy): A Geoturistic Trail Route in the Pollino UNESCO Global Geopark

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## Abstract

The Pollino National Park, located on the Calabria-Lucanian boundary (Italy), was included in the European Network of UNESCO GEOPARKS in 2015 because it is characterized by notable geodiversity regarding geological-structural, geomorphological, hydrogeological and paleontological peculiarities. In the Pollino UNESCO Global Geopark, 69 Geosites have been defined. The definition of geosite derives from the combination of two words, one Greek “geo” (Earth) and the other Latin “situs” (site) which means geological site or site of geological interest. Geosites have great landscape and environmental value, and their geological characterization and accessibility are particularly important. In this study, we focused on the geosite of *Timpa delle Murge*, near the village of Terranova del Pollino (PZ) in the Pollino Massif. The Geotourism route, starting from the village of Terranova del Pollino, testifies to the existence of the ocean basin (Tethys) at around 1300 m and its subsequent closure. Along the route it is possible to observe the ophiolitic rocks and a detailed panel, which explains how, by following the geological itinerary described, you are walking on the bottom of what was once an ocean. The Geotourism route is easily practicable with well-developed roads and there are several hotels in the area which make the area attractive for Pollino tourism. The Geoturistic route is valuable from both a touristic and scientific aspects, and for these regions it is important to try to improve its knowledge not only for its territory but also to more distant territories that can benefit of its peculiarities.

**Keywords** Geosites · Geoturistic trail · Ophiolites · Pollino UNESCO Global Geopark · Southern Italy

## Introduction

Ophiolite sequences are geological formations of great interest, since they act as “fossil fragments” of ancient ocean floors, providing a direct window into mantle composition and the tectonic processes that drive the closure of oceans and the birth of mountain ranges. Due to their geological, geodynamic and tectonic importance, these rock formations, which is found in only a few areas of Italy, has

been widely studied by recent and less recent research studies (Amodio Morelli et al., 1976; Lanzafame et al. 1978; Munich 1993; Spadea 1994; Gueguen et al. 1998; Cello and Mazzoli 1999; Sansone et al. 2011, 2012a, b; Sansone and Rizzo 2012; Dilek and Furnes 2014; Franceschelli et al. 2021; Fancello et al. 2022).

In the area of *Timpa delle Murge*, rocks of ophiolitic suites can be observed and are relatively rare in the national panorama, which characterizes the landscape of the Pollino UNESCO Global Geopark which represents one of the most fascinating geological “archives” of the Mediterranean.

This study describes the Geological Route of the *Timpa delle Murge* ophiolitic sequence which is one of the most significant geological outcrops in the Southern Apennines, serving as a preserved fragment of the ancient Tethys Ocean and representing the most complete ophiolitic sequence in the region (Spadea 1979; Sansone et al. 2011).

The geo-tourist itinerary outlines the evidence of the formation and subsequent closure of the Tethys Ocean basin.

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The route includes stops with detailed boards explaining that visitors are walking on the bottom of an ancient ocean. The geological path, through four stops, shows the origin and evolution of the exposed rocks, allowing visitors to understand the area's geological and environmental changes over millions of years. Along this path, visitors can observe parts of the ancient Jurassic Ocean and touch various types of rocks from the Tethys oceanic crust. The itinerary is shown on a 1:75000 geological map and a hiking map. Points, called Stops, are marked on the map and some have panels with QR codes for additional information. This work aims to demonstrate how the rocks of the Pollino Massif are not just a geological outcrop, but a narrative of our planet's past and a key resource for the territory's identity. The Pollino UNESCO Global Geopark's geological and landscape features are a valuable cultural heritage that must be preserved for future generations to appreciate and learn from.

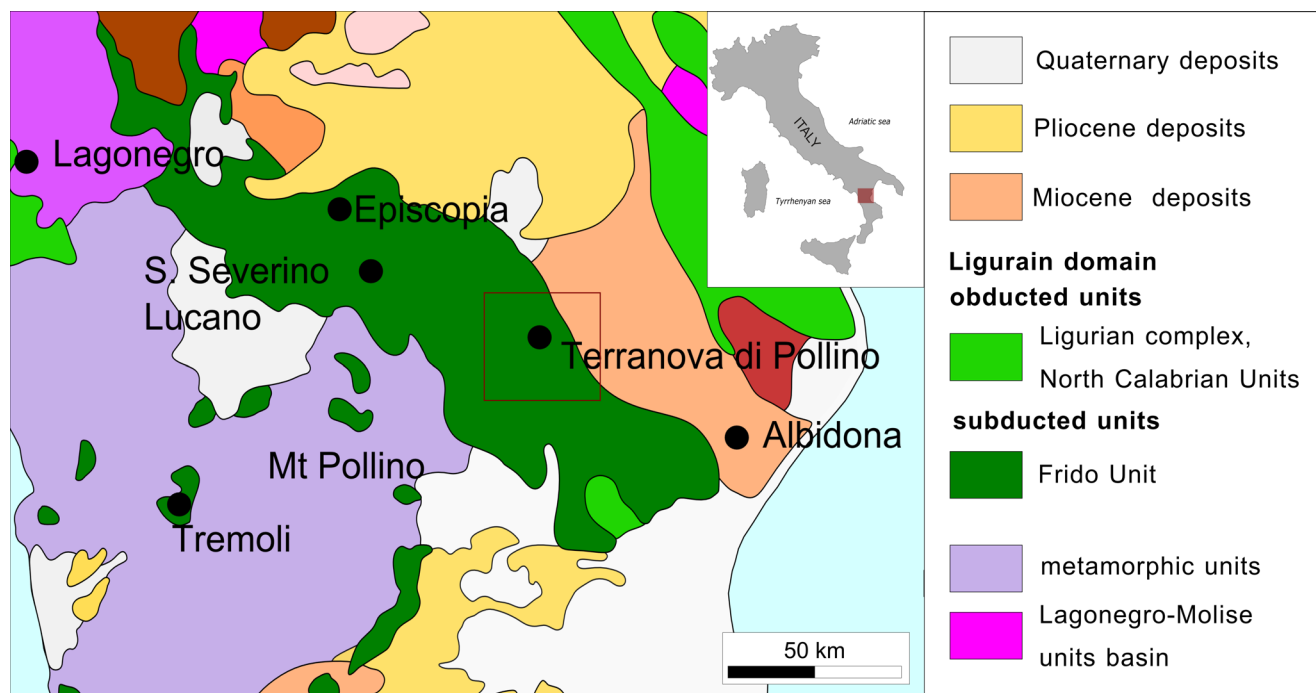
## Geology of the Studied Area

In the Pollino Massif of the southern Apennines (Fig. 1), there are well exposed rocks with peculiar characteristics, known as ophiolitic sequences. These rocks, fascinating in their beauty, are especially concentrated near to the Calabria-Lucanian boundary. They represent fragments of oceanic crust with a relatively deep-sea sedimentary cover and are evidence of an ancient Jurassic oceanic basin, known in

the literature as Tethys (Western Tethys according to Maroni et al. 1998 or Alpine Tethys according to Stampfli et al. 2002).

The southern Apennines chain is one of fold and thrust structures formed of different tectonic units from the Apulian and African Mesozoic paleo margins. On a regional scale, the different tectonic units in the Calabro-Lucanian boundary are the results of compressive tectonics which, in an initial stage, involved the rocks of the ophiolitic sequence and, later, the rocks of the Mesozoic-tertiary platform made up of the limestone dolomitic successions (Fig. 2). Therefore, the geological characteristics of the rocks that crop out in the Calabro-Lucanian sector of the southern Apennine area constitute fundamental elements which allow us to reconstruct the main evolutionary stages of this orogen.

The Pollino UNESCO Global Geopark is located in the southern Apennine chain at the Calabria-Lucanian boundary and consists of thrust belts that derived from the convergence between African and European plates (Knott 1987, 1994) in the Oligocene and Pleistocene (Patacca and Scandone 2007) and includes the Ligurian ocean ophiolitic crust (Knott 1994; Monaco and Tortorici 1995a, b). The Liguride Complex also defined Liguride Units consists of rocks of oceanic and continental crust and sedimentary sequences (Vezzani 1969; Monaco and Tortorici 1995a, b; Laurita et al. 2014). The Liguride Complex has been subdivided from bottom to top in different tectonic units: the North Calabrian Unit or the non-metamorphic flysch Calabro-Lucano Unit (Monaco et al. 1995; Cavalcante et al. 2009; Tortorici



**Fig. 1** Geological sketch map of Southern Italy (modified after Rizzo et al. 2018) with the localization of *Timpa delle Murge* area

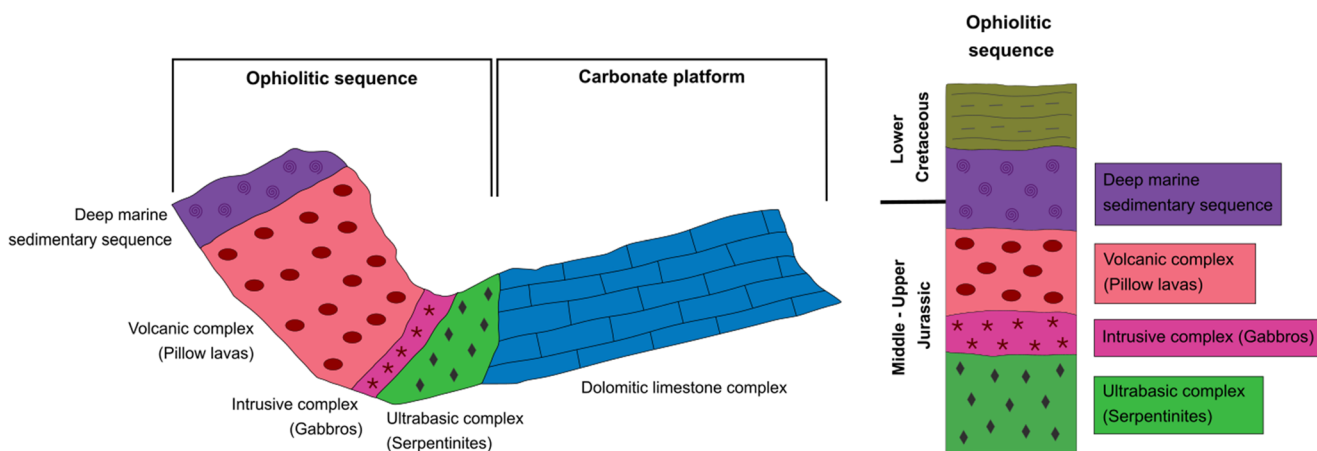


Fig. 2 Relationship between platform calcareous domains and ophiolitic rocks in *Timpa delle Murge* area, at the Calabrian-Lucanian boundary

et al. 2009), the Frido Unit and the Crystalline metamorphic Units (Bonardi et al. 1988; Di Leo et al. 2005). The metamorphosed Frido Unit, which tectonically overlies the North Calabrian Unit, consists of a sedimentary sequence of low-grade phyllites, meta-arenites, meta limestones, calcschists) (Rizzo et al. 2016; Paternoster et al. 2021) with blocks of oceanic and continental crust rocks (Knott 1994) (Fig. 3). Oceanic crust rocks as ophiolites consist of serpentinites with metadolerite dykes and metabasalts (Sansone et al. 2011, 2012a, b; Sansone and Rizzo 2012; Dichicco et al. 2015, 2017; Bloise et al. 2017; Rizzo et al. 2016, 2018). Some authors (Laurita et al. 2014) stated that the slivers of continental crust in the Frido Unit are a thrust fault that delimits the upper portion of the Frido Unit from a lower portion. The North Calabrian Unit, which exhibits no signs of orogenic metamorphism, covers the Crete Nere Formation, the Saraceno Formation, and the Albidona Formation (Di Leo et al. 2005). This unit is characterized by a pelitic matrix containing blocks of ophiolites, pelagic sediments, and turbiditic sequences (Tortorici et al. 2009). Sansone et al. (2012a, b) have documented that this unit has undergone oceanic alteration.

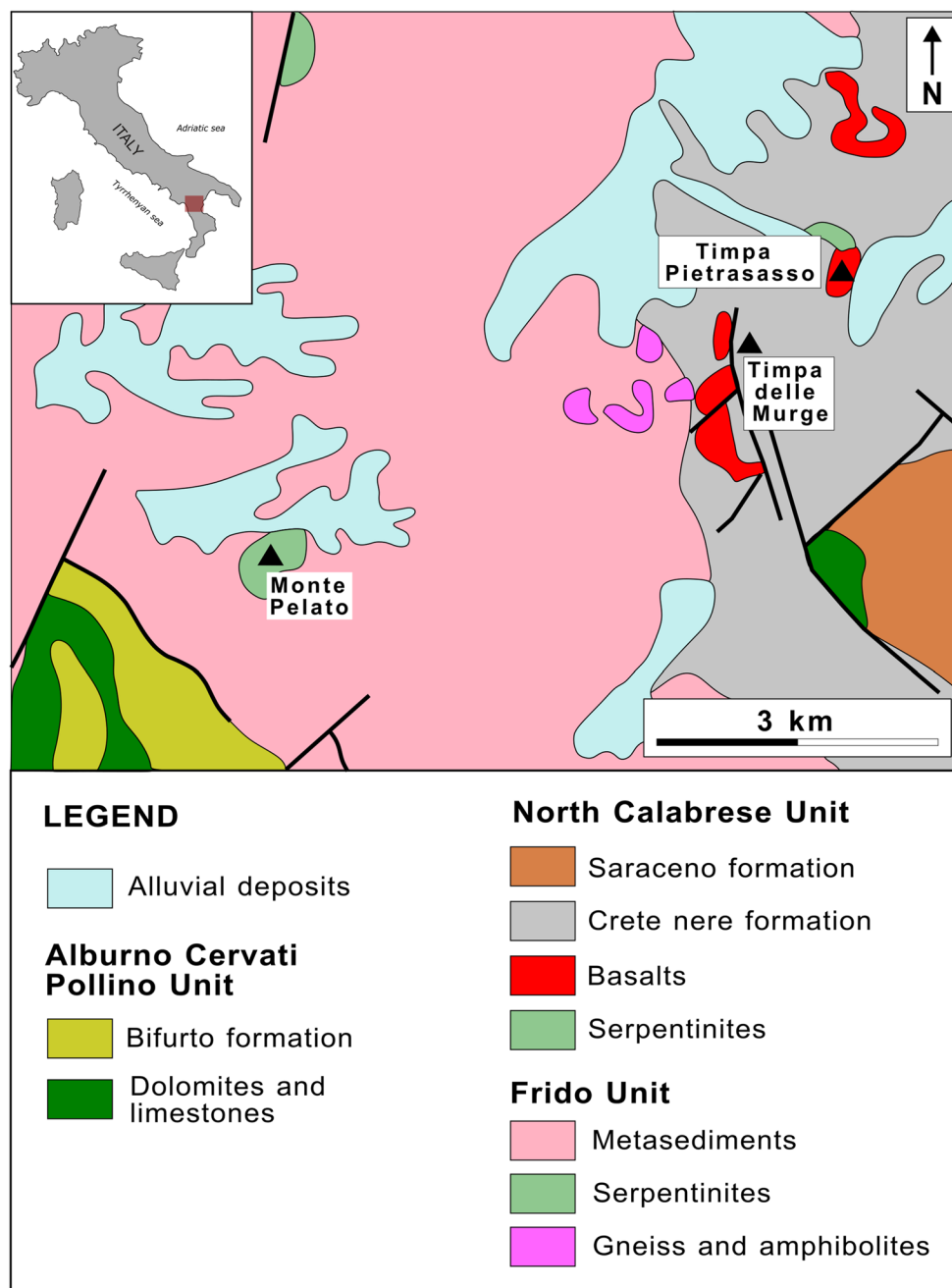
### Timpa Delle Murge Ophiolitic Sequence

In the southern Apennine chain, ophiolites are widely found on the northeastern slope of the Pollino UNESCO Global Geopark. These rocks formed at mid-ocean ridges about 150–170 MA ago during the opening of the Tethys Ocean. They later became part of the southern Apennines through orogenic processes, playing a crucial role in understanding orogeny and plate reconstruction. Ophiolites are remains of a fossil oceanic lithosphere Late Cretaceous-Oligocene age (Knott 1987, 1994; Monaco 1993; Mazzoli 1998; Cello and Mazzoli 1999), resulting from north-westward subduction of

the Jurassic western Tethys below the European continental margin (Dewey et al. 1989; Bortolotti and Principi 2005); some authors (Vezzani 1969; Amodio-Morelli et al. 1976; Spadea, 1976, 1982, 1994; Knott 1987, 1994; Lanzafame et al. 1979; Tortorici et al. 2009) have been attributed ophiolites to the Jurassic Tethyan ocean. Ophiolitic rocks are present both in the Frido Unit and in the North Calabrian Unit. In the Frido Unit, the ophiolitic rocks are mainly formed by serpentinites derived from a lherzolitite and subordinately harzburgitic mantle (Sansone et al. 2011, 2012a, b; Dichicco et al. 2015; Dichicco et al. 2017) and secondarily by meta gabbros, metabasalts, diabases and with sedimentary cover (Spadea, 1982, 1994). The *Timpa delle Murge* ophiolites, belonging to North Calabrian Unit, do not exhibit any subduction-related high-pressure metamorphism (Lanzafame et al. 1978; Bonardi et al. 1988). They are composed of scarce Mg-gabbro cumulates (Spadea 1979) and stratigraphically overlined by pillow lavas pillow breccias, hyaloclastites, diabases. The sedimentary cover comprises siliceous shales, radiolarian cherts and limestones (Lanzafame et al. 1979).

The ophiolitic sequence at *Timpa delle Murge* (Fig. 4) comprises dark green serpentinites, which are tectonized and visible in small outcrops at the base of the sequence. Ascending the sequence, small bodies of gabbro, often of the euphotid type, can be observed. These exhibit both granular and porphyritic textures and contain clinopyroxene with a diallage composition. The effusive rocks are primarily basalts displaying pillow structures characterized by radial fractures formed due to thermal contraction during solidification. These pillows and associated pillows breccias are cemented by a hyaloclastic matrix that is frequently chloritized, exhibiting red and green colours. The sedimentary cover includes siliceous shales followed by a range of red and green radiolarites from the Late Jurassic, which continuously transition upwards to pinkish marly limestone. Radiolarites have nodular structures, highlighted

**Fig. 3** Schematic geological map of the northeastern area of the Pollino Massif (modified after Laurita et al. 2009)



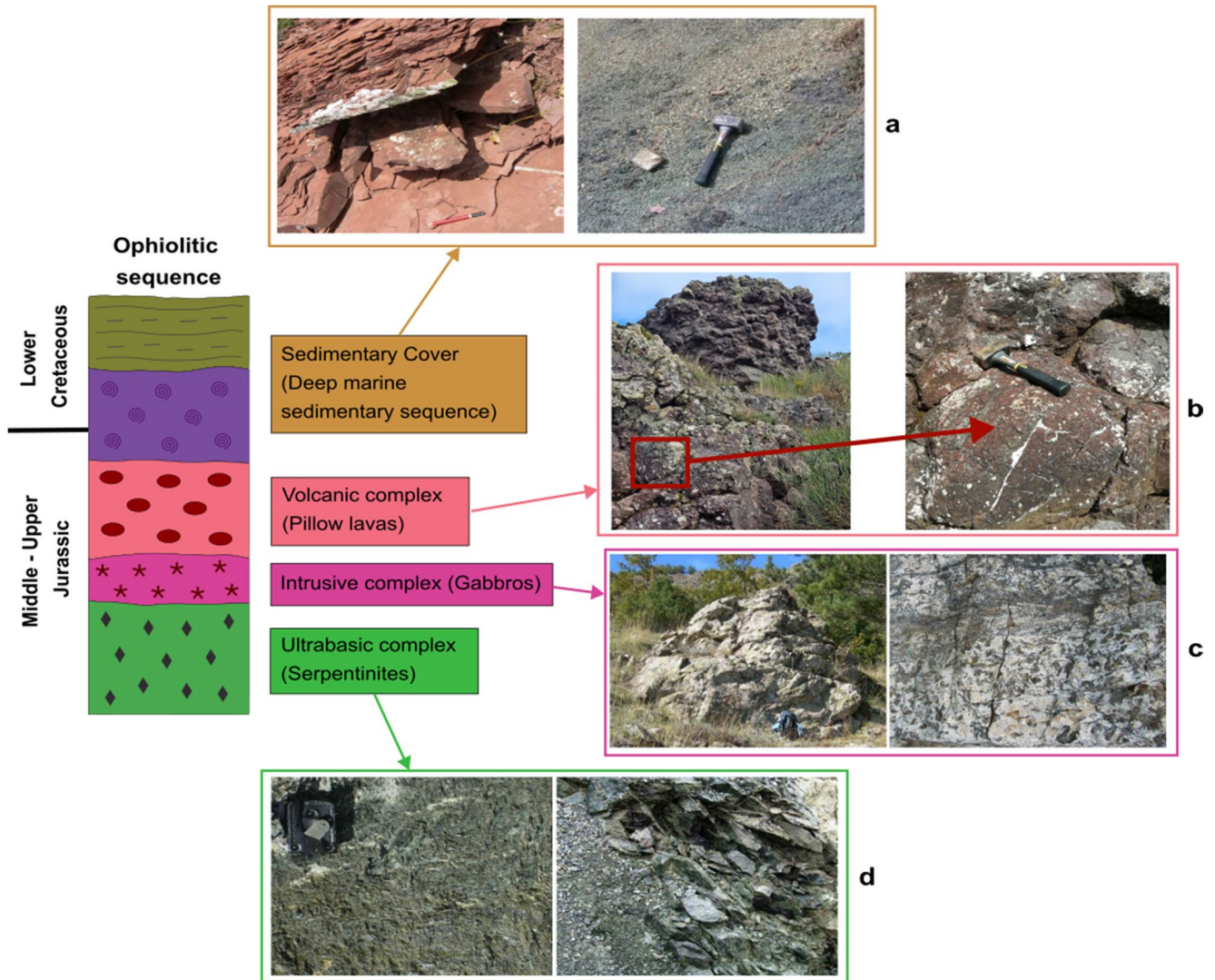
by the chromatic variations of the flint. This is followed by variegated clays containing some layers of quartz-arenites.

### The Geoturistic Trail Route

The Geoturistic trail route is located at Terranova del Pollino (PZ), with a total length of 720 m, and is composed of four stops (Fig. 5). The Geoturistic trail route aims to describe the geological heritage found in *Timpa delle Murge* and this

description has been organized together with explanatory panels along a “geological hiking route” (Fig. 6).

Along this itinerary, it i.a. possible to observe the different portions of the ancient Jurassic Ocean and touch the different rock types of the Tethys oceanic crust. The route stops are the following: Stop 1: the ultrabasic complex, the dominant rocks of which are serpentinites (Fig. 7); Stop 2: the intrusive complex in which gabbros are present (Fig. 8); Stop 3: the volcanic complex, consisting of basalt lavas, often with a pillow-like structure (Fig. 9); Stop 4: an



**Fig. 4** Columnar section of the *Timpa delle Murge* ophiolitic sequence with selected photographs. (a) serpentinites; (b) gabbros of the intrusive complex; (c) pillow lavas of the volcanic complex; (d) pelagic sedimentary rocks

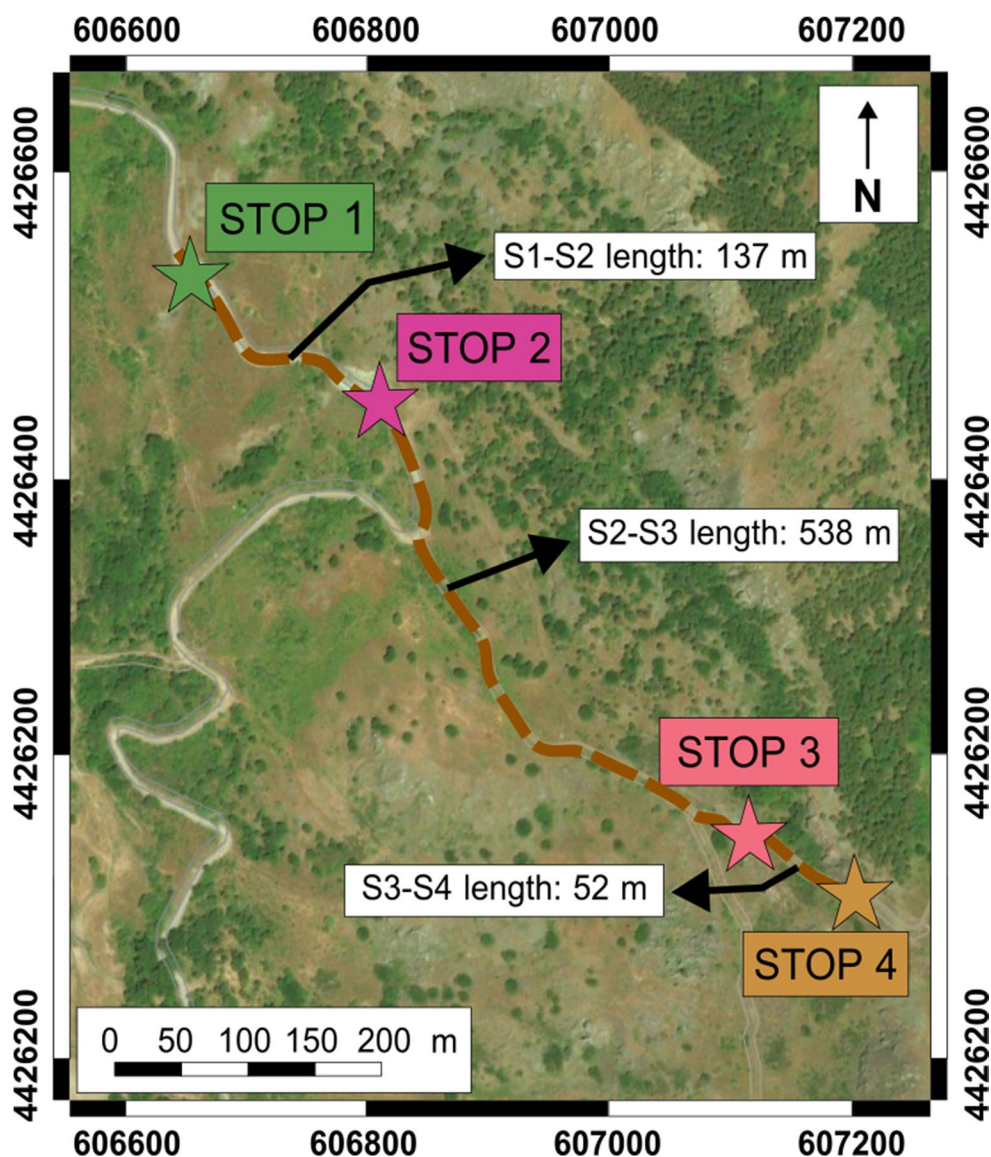
overlying sedimentary series including deep sea deposits (radiolarites, cherts and shales) (Fig. 10). This geological hike/study might interest scientists from around the world because their attention will render it possible to identify those rocks which are difficult to study due to their having emerged from the bottom of the oceans. It was used to identify dark green rocks which could flake and leave a surface resembling the skin of a snake (Kerr, 2019). Following oceanographic research which permitted samples collection from the Atlantic Ocean to be compared with others from the Pollino massif, revealing a consistent presence of sedimentary series and the pillow structure of the volcanic rocks, it was possible to identify the oceanic origin of the Pollino rocks. This attracts the attention of international scientists because it allows us to learn about rocks that are difficult to study because they emerge on the ocean floor.

## The Pollino Geoturistic Trail Route Stops

### Stop 1. Ultrabasic Complex – Serpentinites

Serpentinite, or “snakestone,” resembles snakeskin, which is why it is called ophiolite. Millions of years ago, the Tethys Ocean opened, and oceanic lithosphere fragments were tectonically displaced onto continents, forming ophiolitic suite rocks. These rocks result from metamorphic transformation in water-rich environments of original peridotites (ultrabasic rocks mainly of olivine). They are rich in magnesium, iron, nickel, and chromium. In outcrops, they appear barren with minimal soil cover and distinct shapes. Serpentinites have a proto-mylonitic texture, and a schistosity defined by recrystallized serpentine, clinopyroxene, and opaque minerals. The rocks in the area contain veins of

**Fig. 5** Satellite image indicating the Geoturistic hiking route and the stop numbers with the route distances



serpentine, calcite, and occasionally amphibole. The mineralogical composition includes primary minerals such as serpentine, olivine, orthopyroxene, clinopyroxene, amphibole, calcite, and chlorite, along with accessory minerals like spinel, magnetite, and other opaque minerals.

### Stop 2. Intrusive Complex – Gabbros

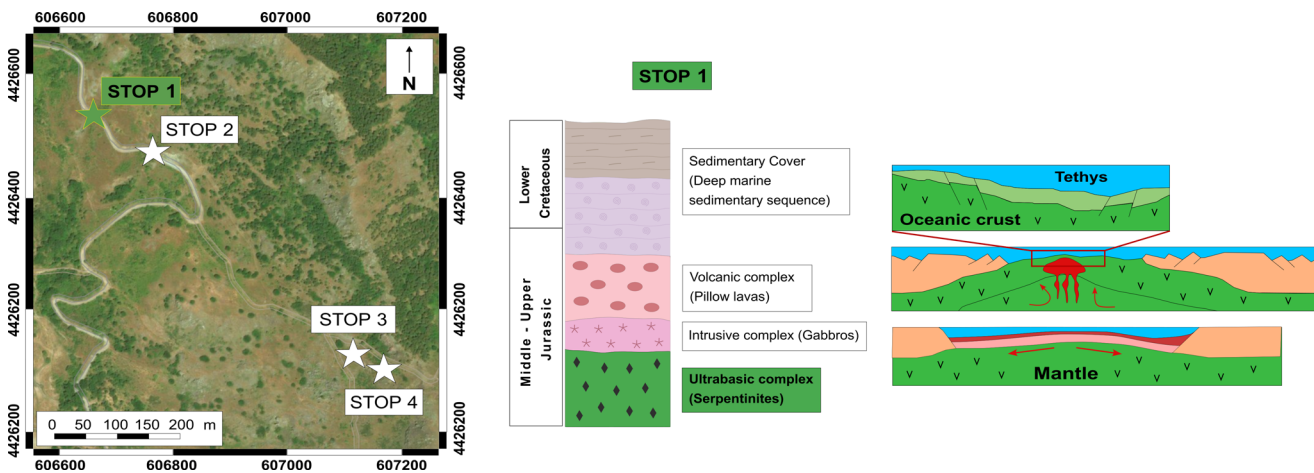
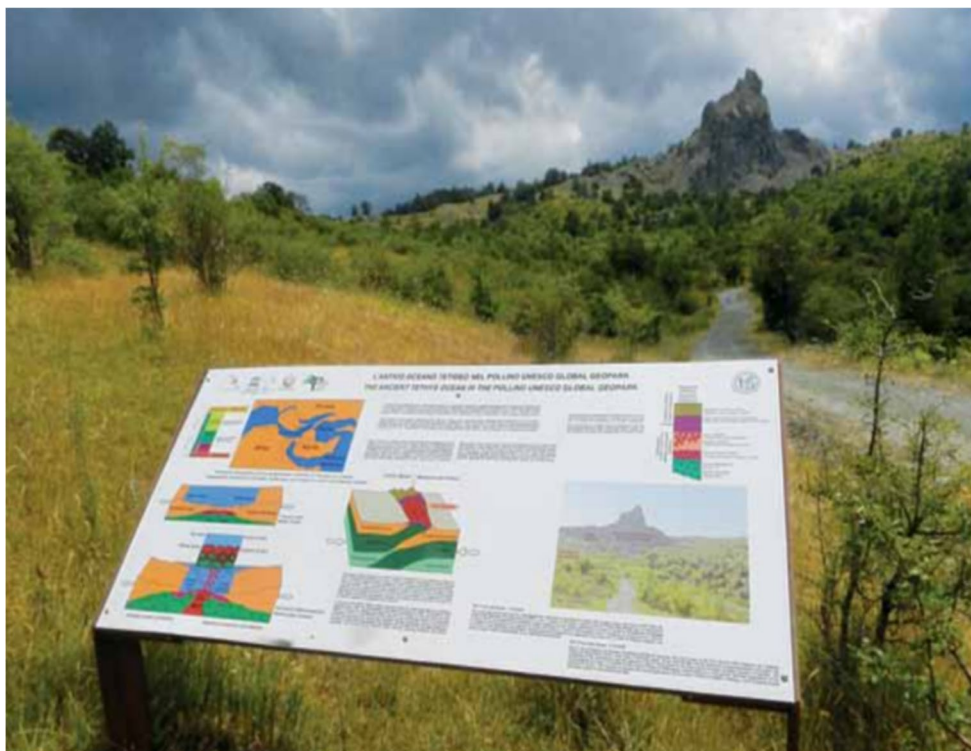
The gabbros of the North Calabrian Unit are only a small part of the ophiolites from the Calabria-Lucania area and occur as bodies not exceeding one km<sup>3</sup> in volume (Beccaluva et al. 1984; Rizzo et al. 2018). They consist mainly of sursuritized plagioclase, olivine and relics of clinopyroxene (diopside according to Beccaluva et al. 1984; or diallage according to Lanzafame et al. 1978). The occurrence of brown hornblende suggests a recrystallization under amphibolite followed by greenschist facies conditions

(Beccaluva et al. 1984). The nearby diabase shows intersertal, subophitic textures (Lanzafame et al. 1978). Metamorphism of the gabbros and diabases is characterized by prehnite-pumpellyite facies to greenschist facies mineral assemblages. The oceanic metamorphic evolution is characterized by albite, chlorite, tremolitic hornblende, white mica and epidote. Pillows and pillow breccias preserve their original structure and minerals. The prevalent basaltic rocks have intersertal structure, while porphyric rocks are rare (Lanzafame et al. 1978, 1979; Bonardi et al. 1988).

### Stop 3. Volcanic Complex - Pillow Lava

The pillow lavas exhibit porphyric texture, variolitic rims, and a hyaloclastic matrix. They are intersected by calcite veins with polysynthetic twinning and rhombohedral cleavage. The mineral assemblage includes phenocrystals of

**Fig. 6** Explanatory panels along the geological hiking route



**Fig. 7** Stop 1 - The ultrabasic complex. On the right, the graphic scheme of the first main phases of the opening of a new ocean domain

plagioclase and clinopyroxene embedded in an intersertal plagioclase matrix. Plagioclase appears as euhedral to subhedral phenocrysts, often altered by secondary minerals like sericite and saussurite. Clinopyroxene grains, predominantly augite, are frequently replaced by chlorite. Chlorite crystals and other secondary minerals form lamellar or radial aggregates. Pumpellyite fills veins, while prehnite forms radiused fibrous aggregates. Opaque minerals are dendritic in the groundmass, and clay minerals replace plagioclase and clinopyroxene, appearing in patches within the glassy groundmass.

**Stop 4. Sedimentary Cover**

The sedimentary cover emerges in the upper part of the ophiolitic sequence of Timpa delle Murge, above the volcanic complex. The characterizing lithotypes are represented by radiolarites on which a level of red and green argillite rests. The radiolarites, red in colour, emerge, at the sampling site, with stratigraphic contact on the pillow lavas in a variable thickness range. Lamination surfaces are visible and calcite veins subparallel to the stratification can also be seen. Radiolarites also alternate with red marly limestones

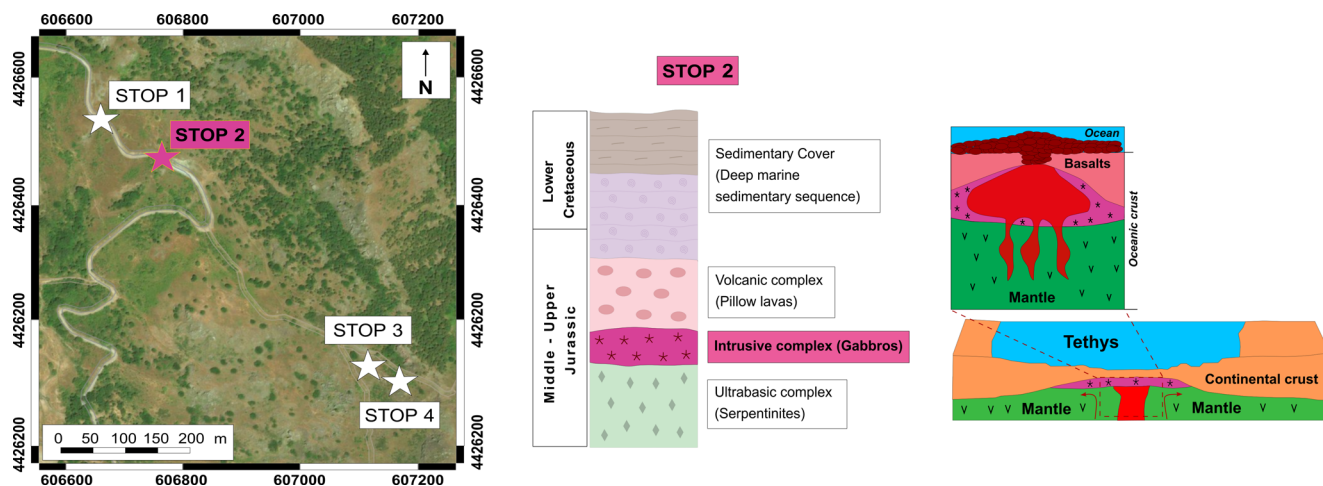


Fig. 8 Stop 2 - The intrusive complex. On the right, a schematic focus of the movement of molten material from the mantle causing the outflow of basaltic lavas

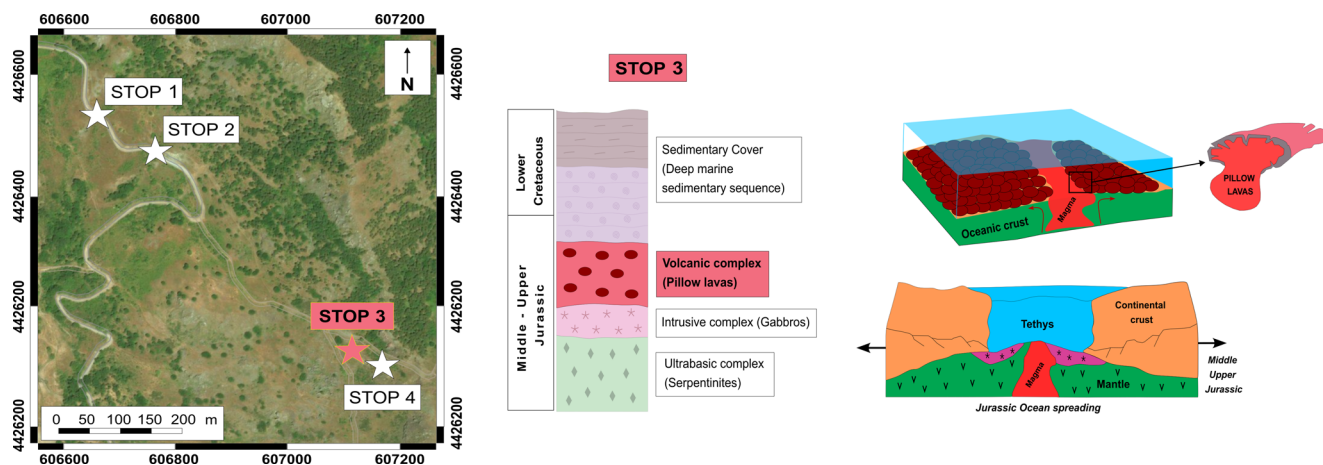


Fig. 9 Stop 3 - The volcanic complex. On the right, expansion and tearing of the continental crust with generation of a new oceanic crust with the focus of the outflow which generated the pillow lavas

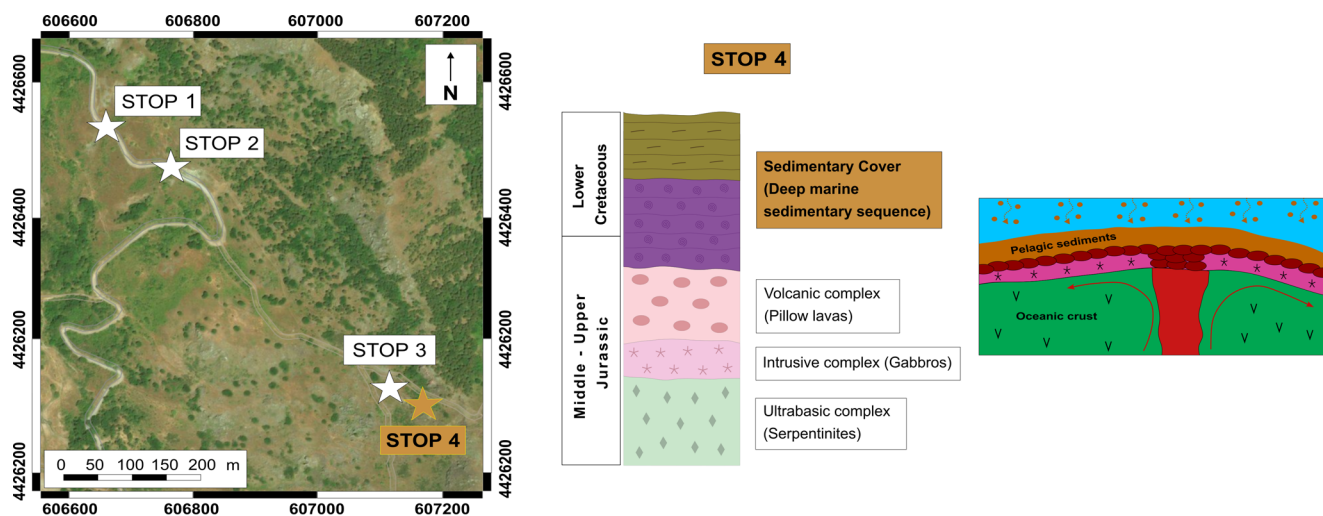


Fig. 10 Stop 4 - The sedimentary cover

containing thin intercalations of marl and calcareous marl. Above the radiolarites lies an interval of red and green siliceous shales, which are associated with very thin layers of fine-grained quartz arenites.

## Conclusions

The ophiolitic sequence of Timpa delle Murge represents a geological heritage of inestimable value, both for the understanding of the geological and geodynamic processes that have shaped the region, and for its tourist and cultural potential. Its peculiar and complex stratigraphy offers scholars an important testimony of the evolution of the oceanic crust, while its geomorphology and landscapes attract tourists looking for immersive experiences in nature. Preserving this site means not only protecting a unique ecosystem, but also ensuring scholars, scientists and future generations the opportunity to study and admire a key element of the geological history of the area. Enhancement through educational tours, guided excursions and awareness-raising initiatives can promote greater awareness of its scientific importance and promote sustainable tourism, which combines research and responsible use of the natural heritage. The integration between environmental protection and tourism development could transform the territory of *Timpa delle Murge*, in the Pollino UNESCO Global Geopark, into an international reference point for geo-conservation, demonstrating how scientific knowledge can translate into opportunities for cultural and economic enhancement. In this context, the Pollino UNESCO Global Geopark plays a key role, offering a virtuous example of biodiversity conservation and the promotion of nature tourism. Its spectacular geological formations, contribute to making the area a privileged destination for hikers, scholars and nature lovers, reinforcing the need for protection policies that guarantee a balance between enhancement and conservation of the territory.

**Author Contributions** Conception: Roberto Buccione, Giovanni Mongelli, Giovanna Rizzo. Data Acquisition: Jeanne Caggiano, Salvatore Laurita, Elena Marrocchino. Interpretation: Giovanna Rizzo, Salvatore Laurita, Egidio Calabrese, Luigi Bloise, Elena Marrocchino. Writing and review: Roberto Buccione, Giovanni Mongelli, Giovanna Rizzo, Carmela Vaccaro

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## Declarations

**Conflict of Interest** The authors declare no competing interests.

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## References

- Amodio-Morelli L, Bonardi G, Colonna V, Dietrich D, Giunta G, Ippolito F, Liguori V, Lorenzoni S, Paglionico A, Perrone V, Piccarreta G, Russo M, Scandone P, Zanettin-Lorenzoni E, Zupetta A (1976) Memorie della Società Geologica Italiana 17:1–60L'Arco calabro-peloritano nell'orogene Appenninico-Maghrebide
- Beccaluva L, Macciotta G, Piccardo GB, Zeda O (1984) Petrology of lherzolitic rocks from the Northern Apennine ophiolites. *Lithos* 17:299–316
- Bloise A, Catalano M, Critelli T, Apollaro C, Miriello D (2017) Naturally occurring asbestos: potential for human exposure, San Severino Lucano (Basilicata, southern Italy). *Environ Earth Sci* 76:1–13
- Bonardi G, Amore FO, Ciampo G, De Capoa P, Micconet P, Perrone V (1988) Il complesso Liguride. *Auct: stato delle conoscenze e problemi aperti sulla sua evoluzione pre-Appenninica e i suoi rapporti con l'Arco Calabro*. *Mem Soc Geol It* 41:17–35
- Bortolotti V, Principi G (2005) Tethyan ophiolites and Pangea break up. *Island Arc* 14:442–470
- Cavalcante F, Belviso C, Finizio F, Lettino A, Fiore S (2009) In: Fiore S (ed) Geological Map of Liguride Unit Area of the Pollino (Basilicata Region): New Data Geological, Mineralogical and Petrographic. Digilabs, Bari, pp 36. [https://rsdi.regione.basilicata.it/downloadProd/canoa/note\\_illustrative.pdf](https://rsdi.regione.basilicata.it/downloadProd/canoa/note_illustrative.pdf)
- Cello G, Mazzoli S (1999) Apennine tectonics in southern Italy: A review. *J Geodyn* 27:191–211
- Dewey JF, Helman ML, Knott SD, Turco E, Hutton DHW (1989) Kinematics of the western Mediterranean. In: Coward MP, Dietrich D, Park RG (eds) *Alpine Tectonics*, vol 45. Geological Society, London, pp 265–283
- Di Leo P, Schiattarella M, Cuadros J, Cullers R (2005) Clay mineralogy, geochemistry and structural setting of the ophiolite-bearing units from southern Italy: a multidisciplinary approach to assess tectonics history and exhumation modalities, vol 10. *Atti Tici-nensi di Scienze della Terra*, pp 87–93
- Dichicco MC, Laurita S, Paternoster M, Rizzo G, Sinisi R, Mongelli G (2015) Serpentinite Carbonation for CO<sub>2</sub> Sequestration in the Southern Apennines: Preliminary Study. *Energy Procedia* 76:477–486
- Dichicco MC, De Bonis A, Mongelli G, Rizzo G, Sinisi R (2017)  $\mu$ -Raman spectroscopy and X-ray diffraction of asbestos' minerals for geo-environmental monitoring: The case of the southern Apennines natural sources. *Appl Clay Sci* 141:292–299
- Dilek Y, Furnes H (2014) Ophiolites and their origins. *Elements* 10(2):93–100

- Fancello D, Columbu S, Cruciani G, Dulcetta L, Franceschelli M (2022) Geological and archaeological heritage in the Mediterranean coasts: Proposal and quantitative assessment of new geosites in SW Sardinia (Italy). *Front Earth Sci* 10:910990
- Franceschelli M, Columbu S, Elter FM, Cruciani G (2021) Giant Garnet Crystals in Wollastonite–Grossularite Diopside-Bearing Marbles from Tamarispa (NE Sardinia, Italy): Geosite Potential, Conservation, and Evaluation as Part of a. *Reg Environ Resource Geoheritage* 13(4):96
- Gueguen E, Doglioni C, Fernandez M (1998) On the post-25 Ma geodynamic evolution of the western Mediterranean. *Tectonophysics* 298(1–3):259–269
- Kerr A (2019) Classic Rock Tours 2. Exploring a Famous Ophiolite: A Guide to the Bay of Islands Igneous Complex in Gros Morne National Park, Western Newfoundland, Canada. *Geosci Can* 46(3):101–136
- Knott SD (1987) The Liguride Complex of Southern Italy- A Crataceous to Paleogene accretionary wedge. *Tectonophysics* 142:217–226
- Knott SD (1994) Structure, kinematics and metamorphism in the Liguride Complex, southern Apennines. *Italy J Struct Geol* 16:1107–1120
- Lanzafame G, Spadea P, Tortorici L (1978) Provenienza ed evoluzione dei Flysch cretatico-eocenici della regione calabro-lucana. relazioni tra ofioliti e Flysch calabro-lucano, II
- Lanzafame G, Spadea P, Tortorici L (1979) Delazioni stratigrafiche tra le ofioliti e formazione del Frido nella Calabria settentrionale e nell'appennino lucano
- Laurita S, Cavalcante F, Belviso C, Prosser G (2009) The Liguride Complex of the Pollino Area (Southern Apennines): Tectonic setting and preliminary mineralogical data. *Rend Online Società Geologica Italiana* 5:111–114
- Laurita S, Prosser G, Rizzo G, Langone A, Tiepolo M, Laurita A (2014) Geochronological study of zircons from continental crust rocks in the Frido Unit (Southern Apennines). *Int J Earth Sci* 104:179–203
- Marroni M, Molli G, Montanini A, Tribuzio R (1998) The association of continental crust rocks with ophiolites in the Northern Apennines (Italy): implications for the continent-ocean transition in the Western Tethys. *Tectonophysics* 292(Issues 1–2):43–66
- Mazzoli S (1998) The Liguride units of southern Lucania (Italy): structural evolution and exhumation of high-pressure metamorphic rocks. *Rend Lincei* 9:271–291
- Monaco C (1993) Le Unità Liguridi nel confine Calabro-Lucano (Appennino Meridionale): controllo dei dati esistenti, nuovi dati ed interpretazione. *Bollettino della Società Geologica Italiana* 112:751–769
- Monaco C, Tortorici L (1995a) Tectonic role of ophiolite-bearing terranes in the development of the Southern Apennines orogenic belt. *Terra Nova* 7:153–160
- Monaco C, Tortorici L (1995b) Tectonic role of ophiolite-bearing terrains in the development of the Southern Apennines orogenic belt. *Terra Nova* 7:153–160
- Monaco C, Tortorici L, Morten L, Critelli S, Tansi C (1995) Geologia del versante Nord-orientale del Massiccio del Pollino (Confine calabro lucano). Nota illustrativa sintetica alla scala 1:50.000. *Boll. Soc Geol Ital* 114:277–291
- Patacca E, Scandone P (2007) Geology of the southern Apennines. *Bollettino Società Geologica Italiana* (7):75–119
- Paternoster M, Rizzo G, Sinisi R, Vilardi G, Di Palma L, Mongelli G (2021) Natural Hexavalent Chromium in the Pollino Massif Groundwater (Southern Apennines, Italy): Occurrence, Geochemistry and Preliminary Remediation Tests by Means of Innovative Adsorbent Nanomaterials. *Bull Environ Contam Toxicol* 106:421–427
- Rizzo G, Sansone MTC, Perri F, Laurita S (2016) Mineralogy and petrology of the metasedimentary rocks from the Frido Unit (southern Apennines, Italy). *Periodico di Mineralogia* 85:153–168
- Rizzo G, Laurita S, Altenberger U (2018) The Timpa delle Murge ophiolitic gabbros, southern Apennines: Insights from petrology and geochemistry and consequences to the geodynamic setting. *Periodico di Mineralogia* 87:5–20
- Sansone MTC, Rizzo G (2012) Pumpellyite veins in the metadolerite of the Frido Unit (southern Apennines, Italy). *Periodico di Mineralogia* 81:75–92
- Sansone MTC, Rizzo G, Mongelli G (2011) Petrochemical characterization of mafic rocks from Ligurian ophiolites, southern Apennines. *Int Geol Rev* 53:130–156
- Sansone MTC, Prosser G, Rizzo G, Tartarotti P (2012a) Spinel-peridotites of the Frido Unit ophiolites (southern Apennines, Italy): evidence for oceanic evolution. *Periodico Mineralogia* 81:35–59
- Sansone MTC, Tartarotti P, Prosser G, Rizzo G (2012b) From ocean to subduction: the polyphase metamorphic evolution of the Frido unit metadolerite dykes (southern Apennine, Italy). Multiscale structural analysis devoted to the reconstruction of tectonic trajectories in active margins. (eds): G. Gosso, MI. Spalla and M. Zucali, *Journal Virtual Explorer*, Electronic Edition, published online
- Spadea P (1979) Contributo alla conoscenza dei metabasalti ofiolitici della Calabria settentrionale e centrale e dell'Appennino Lucano
- Spadea P (1994) Calabria-Lucania ophiolites. *Bollettino di Geofis Teorica e Appl* 36:141–144
- Stampfli GM, Borel GD, Marchant R, Mosar J (2002) Western Alps geological constraints on western Tethyan reconstructions. *J Virtual Explorer* 8:77–106
- Tortorici L, Catalano S, Monaco C (2009) Ophiolite-bearing mélanges in southern Italy. *Geol J* 44:153–166
- Vezzani L (1969) La Formazione del Frido (Neocomiano-Aptiano) tra il Pollino ed il Sinni. *Geol Romana* 8:129–176

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