

The Geological Itinerary of Sasso di Castalda: A Journey into the Geological History of the Southern Apennine Thrust-belt (Basilicata, Southern Italy)

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Abstract Sasso di Castalda (20 km south of Potenza in the Southern Apennines thrust-belt) is a village situated on spectacular outcrops of Mesozoic rocks. In order to illustrate the peculiar stratigraphic and structural features of the area, a geological itinerary comprising 15 stops has been developed around the Sasso di Castalda village. The itinerary illustrates the Mesozoic stratigraphy of the deep-sea Lagonegro Basin in an area where the Triassic to Cretaceous evolution of the basin has been studied in great detail. Extensive exposure allows the observation of tectonic structures related to the Miocene to Pleistocene evolution of the Southern Apennine orogeny. The choice of Sasso di Castalda as the starting point for this itinerary is due to the following reasons: (1) the opportunity to observe the thick sedimentary infill of the Lagonegro Basin, within deeply incised natural sections where lithology, stratigraphical contacts and the geometry of the sedimentary bodies are magnificently exposed; (2) the opportunity to examine 3D-fold geometry at different scales; and (3) the opportunity to observe well-exposed post-orogenic faults crosscutting the earlier contractional structures. The itinerary can be used for school teaching purposes at different levels, as well as university courses. In addition, non-geologists frequently follow the itinerary, often guided by expert volunteers.

Keywords Geological itinerary · Southern Apennines · Italy · Mesozoic stratigraphy · Tectonic structures

Introduction

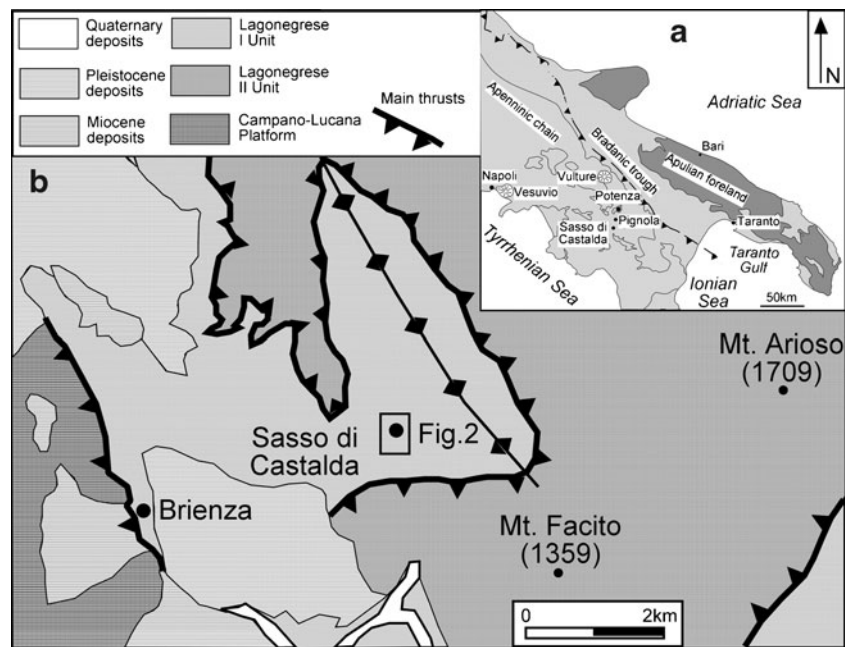
The Lagonegro Basin is peculiar among Tethyan basinal areas in Italy, as deep-sea sedimentation started in the Mid Triassic times, probably during the Ladinian (Wood 1981; Ciarapica and Passeri 2005) and continued throughout the Mesozoic and Cenozoic. Other deep-sea basins that underwent major subsidence during the Mid Triassic (e.g. the Hallstatt-Meliata ‘ocean’ or the Dolomites area in the Austroalpine/Southern Alps) closed during the Late Triassic or Early Jurassic, due to the development of the Hallstatt-Meliata suture (Neubauer et al. 2000). The particular setting of the Lagonegro Basin consequently allowed the preservation of a long stratigraphical record in a deep-sea environment, which is unusual in the Alpine–Apennine chain. This record comprises a thick multilayer sequence, consisting of well-bedded limestone and chert, which favoured the formation of spectacular folds, with kink and chevron geometry, when the Lagonegro units were incorporated in the Apennine chain during the Mid Miocene–Pliocene times.

The peculiar stratigraphic and structural features of the Sasso di Castalda area (Fig. 1a, b) has inspired several studies from the end of the nineteenth century (De Lorenzo 1896). Scandone (1967, 1972) referred the “Lagonegro–Sasso di Castalda facies” to the distal part of the Lagonegro Basin. De Wever and Miconnet (1985) and Miconnet (1988) showed that deep-sea sedimentation below the CCD started earlier in the Lagonegro and Sasso di Castalda areas when compared to other sectors of the basin. A key feature of the area is the presence of the Monte Facito Formation, which forms the base of the Lagonegro succession. This is among the oldest formations in the Apennine thrust-belt, and its type locality has been defined 3 km SE of Sasso di Castalda village (Scandone 1967).

Summarizing, outcrops in the Sasso di Castalda area provide fundamental information on the stratigraphy and

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Fig. 1 **a** Geological sketch map of the Southern Apennine thrust-belt; the location of the Sasso di Castalda village is indicated. **b** Schematic geological map of the relevant sector of the Southern Apennines. Thrusts separating the main tectonic units of the Southern Apennine are outlined



paleoenvironmental evolution of the Tethyan domain in the Mesozoic and give important indications on the structure and the tectonic evolution of the Southern Apennines. For this reason, they are a key part of the geological heritage of Southern Italy, as well as having an important scientific value for research in the geosciences. In addition, non-professional visitors are also able to read the Mesozoic stratigraphy of the Sasso di Castalda area and to understand simple tectonic structures, and easily distinguish different formations by clear differences in colour in the extensive exposures. The outcrops are consequently suitable for use in geoconservation processes (Carcavilla et al. 2009; Henriques et al. 2011) including for promoting scientific education in the geosciences and geotourism (Hose 2000).

The key outcrops are located in a landscape dominated by the village of Sasso di Castalda, especially along the tortuous Arenatra stream which is enclosed within a deeply incised valley named La Manca. The village itself developed around the remains of a guard tower ('Il Castello') located on a steep cliff on one side of La Manca. Here, the narrow houses are adapted to the rough morphology of the bedrock as the historical remains frequently rest on important outcrops of Mesozoic rocks that reveal, in a small area, the pre-, syn- and post-orogenic evolution of the Southern Apennine thrust-belt. This unusual distribution of a village on the geological substratum facilitates an interesting journey across history and geology whilst moving within an urban area. Scientific interest, easy access and wide and clear outcrops associated with historical-cultural resources were essential components for the development of the geological itinerary in the Sasso di Castalda village.

In this paper, we will first outline the scientific features of the Sasso di Castalda site, with particular emphasis on the stratigraphy and the tectonic structures, in order to highlight their importance to the geological heritage of the Southern Apennines. Then, we will describe the stops on the geological itinerary, with particular emphasis on the criteria used to select them.

Geological Setting

Sasso di Castalda village is located in the axial sector of the Southern Apennines thrust-belt (Figs. 1 and 2) where a thick pile of sediments mainly deriving from the deformation of a deep-water basin outcrops. This basin, known as the Lagonegro Basin, together with the Campano–Lucana and Apulian platforms, was part of the Meso-Cenozoic northern margin of the African continent facing the Tethys Ocean. From the Oligocene to the Early Pleistocene, during the closure of the Tethys Ocean and the Africa–Europe continental collision, the Lagonegro Basin was completely inverted by contractional tectonics. During the Pleistocene, the Southern Apennines were intensely affected by extensional and strike-slip tectonics (Cello and Mazzoli 1999; Pescatore et al. 1999; Giano et al. 2000), and now, the deposits of the Lagonegro Basin form a huge nappe tectonically sandwiched between the Campano–Lucana and Apulian Platforms.

The birth of the Lagonegro Basin is generally referred to the Early Triassic when, after the opening of Tethys, sedimentation of the shallow-water deposits of the Monte Facito Formation took place. This early stage is marked by

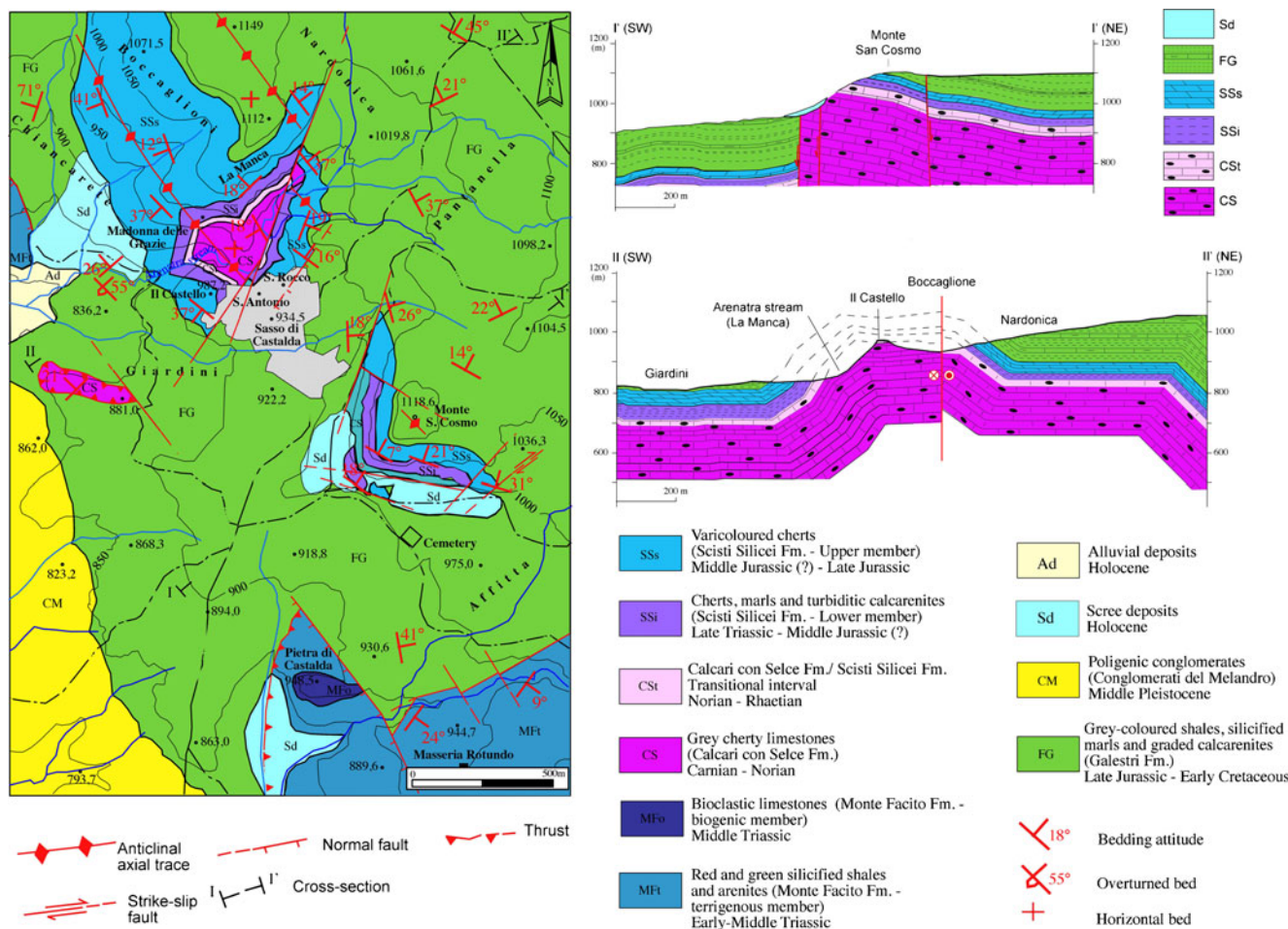


Fig. 2 Detailed geological map and cross-sections of the Sasso di Castalda area

deposition of wave- and storm-influenced clastic sediments and algal-bearing carbonate build-ups. From the Mid Triassic, the Lagonegro Basin began to subside in relation to the adjacent Campano–Lucana and Apulian Platforms, maintaining deep-marine conditions during the remainder of Mesozoic and into part of Cenozoic time.

The deepening phase is progressively recorded in the basin by the deposition of cherty limestones belonging to the Calcarei con Selce Formation (Late Triassic), cherts, jaspers and radiolarites of the Scisti Silicei Formation (Late Triassic–Jurassic), marls and clays of the Galestri Formation (Early–Mid Cretaceous), which as a whole have been grouped within the so-called “calcareo–silico–marnosa” succession (Scandone 1972).

Estimates of the maximum depth reached by the Lagonegro Basin are around 3,000 m (Miconnet 1988; Argnani 2005). After the contractional stages that created the Southern Apennines, the Lagonegro deposits were strongly deformed by a series of thrusts. As a consequence, the succession outcropping in the study area can be subdivided into two main stacked tectonic

units, namely, the Lagonegro I and II units, which are separated by a thrust contact of regional importance (Scandone 1967, 1972; Fig. 3).

The Lagonegro I unit is located in the footwall of the main thrust and comprises distal deposits. This unit lacks in the Early–Middle Triassic portion, represented by the Monte Facito Formation. The Lagonegro II tectonic unit consists of deposits showing more proximal characters compared with the Lagonegro I deposits, as well as the presence of well-developed breccias and slumps deriving from the adjacent Campano–Lucana Platform. In the Sasso di Castalda area, the tectonic contact between the two units is recognizable (Fig. 1b). Here, the Lagonegro I unit is exposed within a tectonic half-window bordered by the Lagonegro II unit, which mainly comprises the Monte Facito and Calcarei con Selce formations.

Along the La Manca gorge, which most of the geological itinerary follows, a thick section of the Lagonegro I succession is spectacularly exposed on the western flank of a kilometre-scale box fold (Fig. 2). In particular, the transitional interval, representing the upper member of the Calcarei

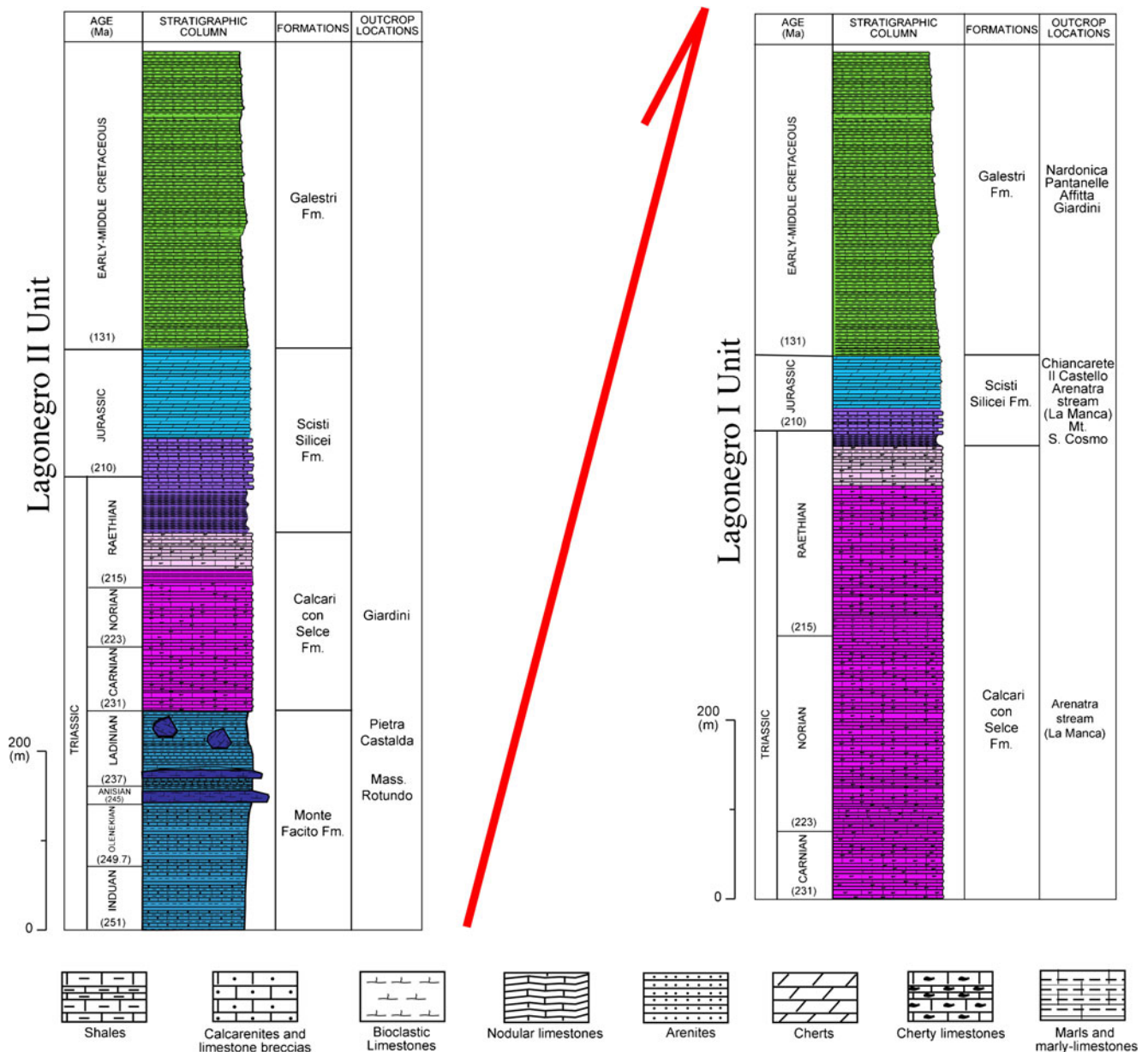


Fig. 3 Stratigraphic columns showing the main differences between the Lagonegro I and II unit successions

con Selce Formation, can be observed in detail (Fig. 3). The deep erosion along the La Manca gorge has led to an excellent exposure of the fold core, and as a consequence, contractional structures related to the Miocene–Pliocene tectonics are clearly visible.

Key Stratigraphical Features

Along the flanks of the La Manca gorge, in the transition between the Calcari con Selce and the Scisti Silicei formations, the Triassic/Jurassic boundary was recognized for the first time in the Lagonegro I succession (Miconnet 1988;

Bertinelli et al. 2005). Detailed descriptions are provided by Amodeo and Baumgartner (1994), Amodeo (1999) and Bertinelli et al. (2005). In particular, the Buccaglione and “Il Castello” sections, described by Bertinelli et al. (2005), were recorded on the northern and southern slopes of the La Manca gorge, respectively.

The stratigraphic scheme adopted on the geological map used to illustrate the Sasso di Castalda itinerary (Fig. 2) is mainly based on the new schemes proposed by recent literature such as that of Bertinelli et al. (2005), with some simplifications. The transitional interval of the Calcari con Selce Formation has been used as proposed in Bertinelli et al. (2005). The Nevèra, Serra

and Buccaglione members, however, have been grouped to form a single stratigraphic unit, the lower member of the Scisti Silicei Formation, and the Acqua Sulfurea Member has been identified as the upper member of the Scisti Silicei Formation.

At the base of the “Il Castello” section, which is one of the key outcrops on the proposed itinerary, a succession of well-bedded cherty limestone with subordinate shales of Norian age (Bertinelli et al. 2005), belonging to the upper part of the Calcari con Selce Formation, outcrop. This interval has been referred to the transitional interval of the Calcari con Selce Formation. In the overlying succession, significant differences in lithological features allow the identification of the two members of the Scisti Silicei Formation (Fig. 3). The lower member, of Rhaetian–Early Jurassic age, consists of well-bedded pelagic deposits, mostly represented by red cherts (formerly Buccaglione Member) grading upwards into varicoloured shales, alternating with base of slope calcarenites and breccias of the former Nevèra and Serra members. These calciclastic deposits are thought to derive from the Campano–Lucana Platform as a consequence of gravity-induced depositional mechanisms. The upper member consists exclusively of marls and green radiolarian cherts—the Acqua Sulfurea Member—and is of Lias–Dogger age (i.e. Lower to Middle Jurassic). Based on a detailed study of conodonts, radiolaria and foraminifera, Bertinelli et al. (2005) located the Triassic/Jurassic boundary within the Nevèra Member, i.e. in the middle–upper portion of the lower member of the scheme used here (Fig. 3).

The marked thickness variations observed in the ‘Nevèra Member’ interval and the diffuse presence of calciclastic deposits at different stratigraphic levels are evidence of the extensional tectonic phase which occurred during Late Triassic and Early Jurassic times in the Mediterranean region as a result of the opening of Tethys. This confirms that in the Lagonegro I domain, subsidence started earlier compared to other more proximal successions of the same basin (Giordano et al. 2011).

Tectonic Structures

In the Sasso di Castalda area, both the contractional and extensional structures responsible for the present tectonic setting of the Southern Apennine thrust-belt are exposed in spectacular outcrops. In particular, mesoscopic and large-scale thrusts, folds and faults are clearly exposed along the La Manca gorge and, more generally, throughout the Sasso di Castalda area. In the area (Fig. 1b), the main thrust doubles the Lagonegro units and carries the Triassic deposits of the Monte Facito Formation (Lagonegro II unit) over

the Early Cretaceous deposits of the Galestri Formation (Lagonegro I unit).

At La Manca, where the Lagonegro I deposits outcrop within a wide tectonic window at the footwall of the main thrust, the south-western limb of a kilometre-scale box fold—the La Manca Fold—can be observed in detail (Fig. 2). On a wider scale, it is possible to demonstrate that the box fold also affects the main thrust plane between the Lagonegro I and Lagonegro II units (Fig. 1b). The presence of an axial culmination in the Sasso di Castalda area results in the exposure of a large portion of the Lagonegro I succession in an area where the Lagonegro II dominates (Fig. 2).

Along the La Manca stream, the two hinge lines of the box fold are oriented around NW–SE and show a gentle plunge towards the NW. In the south-western hinge, the dip of the bedding planes changes from a few degrees to around 70°, showing a well-developed kink geometry. At a smaller scale, a series of parasitic folds, showing an asymmetry consistent with the main anticline, develops along the fold limbs. Examples of parasitic folds are present in the steep south-western limb of the fold, which is well-exposed at the “Il Castello” cliff (Fig. 2). These folds may be associated with low-angle, outcrop-scale thrusts. Other outcrop-scale kink folds located at the base of “Il Castello” cliff and Buccaglione hill are probably unrelated to the development of the main anticline.

The most common structures in the limestones of the Calcari con Selce Formation are bed-parallel stylolites, probably formed due to loading during sedimentation in the Lagonegro basin. In addition, bedding planes are often marked by slickensides and calcite steps, indicating that folding took place by flexural slip processes.

In the area of Sasso di Castalda, the contractional structures are largely dissected by younger faults. In particular, a prominent NNE–SSW-oriented oblique dextral-normal (transtensional) fault cuts the main box fold, interrupting its lateral SE continuity. This structure, here identified as the Arenatra Fault, offsets the Scisti Silicei/Galestri boundary with a throw of about 100 m. A series of shear sense indicators, well visible at the outcrop scale, can be used to assess the kinematics of the fault plane. These structures can be easily recognized on the main slip surface and in the fault damage zone. The most obvious kinematic indicators are represented by oblique slickensides. In addition, strata of the Calcari con Selce Formation at the footwall are dragged along the fault plane assuming a synclinal geometry, in agreement with dextral-normal oblique-slip kinematics. Coherently, a series of en-echelon tension gashes, clearly related to the dextral slip component of the fault, can be observed in the vicinity of the fault plane. The fault has clear effects on the landscape, as part of the Arenatra stream follows its trend.

South of Sasso di Castalda village, other NNE–SSE to E–W trending faults bound the Monte San Cosmo hill, which represents a relict of the north-eastern hinge of the La Manca box fold.

Taken together, these tectonic structures permit the reconstruction of the pre-, syn- and post-orogenic evolution of the Southern Apennine thrust-belt from the evidence from a very small area. The tectonic phases that led to the current geological setting are summarized in Fig. 4.

During the Early Miocene, the Lagonegro Basin succession (Fig. 4a) was affected by contractional deformation leading to the construction of the Southern Apennines (Fig. 4b). In the last stages of this process, a series of large and meso-scale folds, including the La Manca Fold, developed. During the Early Pleistocene, the Southern Apennines were affected by extensional and strike-slip tectonics. This stage is recorded in the Sasso di Castalda area by the activation of the Arenatra Fault (Fig. 4c). From the earlier Quaternary, the Southern Apennine chain has been intensely affected by uplift and erosion, resulting in a significant deepening of watercourses. As a consequence, the Arenatra stream now, in part, follows the strike of the Arenatra Fault (Fig. 4d), which has resulted in the comprehensive exposure of the La Manca Fold along the Il Castello cliff and La Manca Gorge.

The Geological Itinerary

The Sasso di Castalda geological itinerary comprises 15 stops distributed along a 1.2 km circular route through the narrow roads of the older parts of the Sasso di Castalda village, hence forming a closed urban trail. The selected stops are only a few tens of metres apart (Fig. 5). Although the number of stops is high for a geological itinerary that is only 1.2 km long, the first six locations do not show geological outcrops, but include representative geological samples from the area, typically within small shelters. These have been established to transform the narrow streets of the village into an open-air geological museum, which connects the urban area with the outcrops located just beyond. The main geological itinerary comprises eight further stops plus a conclusive panel.

The main reason for choosing Sasso di Castalda for the itinerary is the scientific interest of the area and the presence of important outcrops. However, this choice also derives from the enthusiasm of the local authorities, who provide maintenance for the sites. Currently (2012), the key outcrops within the urban area are protected by a village plan established by the local administration, whereas surrounding areas are not protected. We believe, however, that the

Fig. 4 3D sketch illustrating the evolution of tectonic structures in the Sasso di Castalda area. **a** Original stratigraphy resulting from Triassic to Early Cretaceous sedimentation in the Lagonegro Basin. **b** Box folding consequent to contractional deformation during the construction of the Southern Apennine orogeny. **c** Faulting of the box fold. **d** Present-day situation, after Quaternary uplift and erosion, showing the location of the main topographic features described in the text

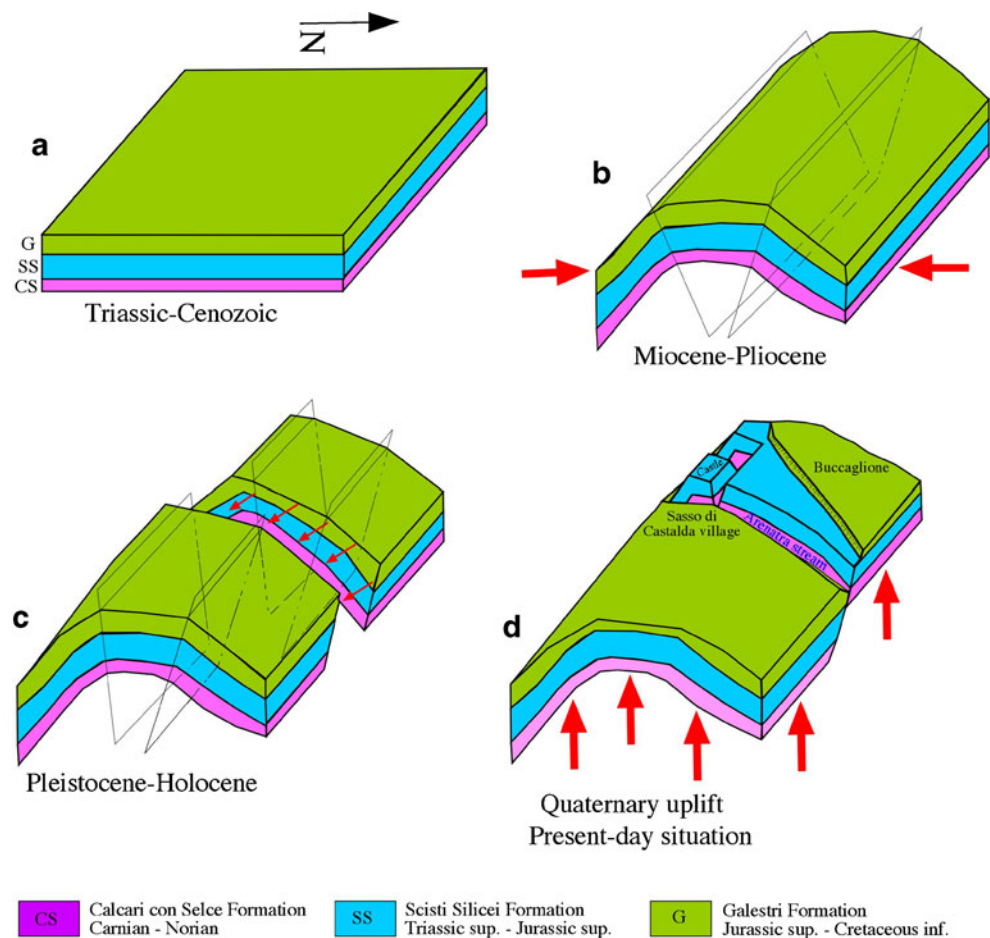
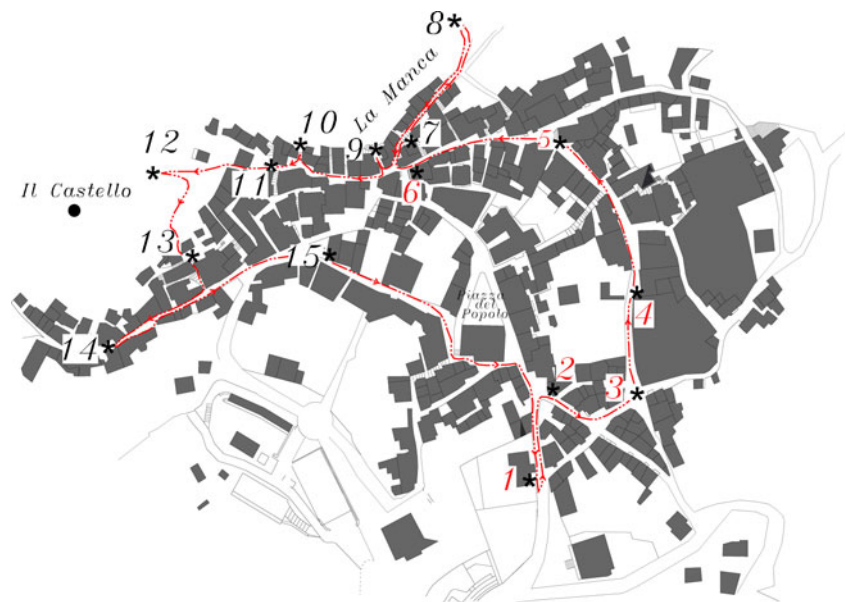


Fig. 5 Map of the urban area of the Sasso di Castalda village, indicating the itinerary (red dashed line) and the stops (numbers). Red numbers (1–6) indicate the first introductory panel and five niches containing samples and explanatory material



geological itinerary may play a fundamental role in the geoconservation (Brilha 2002, 2005; Henriques 2010) of this special area, by raising the awareness of geological heritage within the local population. In the near future, we intend to include this area within the Italian geosites inventory [Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)] as an extended geosite incorporating a series of well-exposed outcrops.

Most stops have been selected to provide the best conditions for making both stratigraphic and structural observations as visitors proceed along the village roads. Covered displays containing samples, and illustrative materials (mainly photographs, drawings and block diagrams) have been sited in key corners of the village, in order to illustrate the overall geology of the area and parts of the stratigraphy. The overall organization of the stops follows a classical scheme where the stratigraphy is mainly demonstrated first, followed by a description of the structural features. In addition, this scheme permits a progressive introduction to the geology of the area, prior to actual field observations.

The itinerary is free of difficult terrain and, therefore, can be easily followed by people of any age. We are preparing illustrative material with variable complexity to make the itinerary accessible to non-geologists and to school students of different levels. Due to the short distance, the full itinerary can be completed in about 2 h at a normal walking pace. Every stop is interpreted by panels assembled in a metallic showcase or within a covered niche, when a representative rock sample is displayed (Fig. 6a, b).

The itinerary starts with a panel containing a brief synthesis of the geology of Sasso di Castalda. The description is supported by an explanation of a detailed geological map with geological cross-sections. A stratigraphic column is also provided. The next five panels (from 2 to 6) are located

within five covered niches which contain representative rock samples and fossils. The panels give a detailed description on the stratigraphy of all the geological formations outcropping in the area. Due to the high lithological variability and fossil content, particular attention is focussed on the Monte Facito Formation, which is illustrated by two panels (2 and 3). Thin section photographs and sketches are also used to explain more clearly the lithology of the considered formations and the related sedimentary environments. The next eight panels (from 7 to 14) give an accurate description of the main geological structures directly visible in the field from panoramic viewpoints or in single outcrops. Near the La Manca gorge, very peculiar outcrops can be seen at the base of some of the houses. Here, numerous photographs, line drawings, block diagrams and sketches help to the interpretation of the structures present. In this group, stop 12 represents an exception where some distinctive sedimentological features related to the Lago-negro deposits can be observed. Finally, the last panel serves as a summary of the main stratigraphical and structural features which have been observed along the geological itinerary.

The panels have been mainly developed for teaching purposes, especially for schools of different levels and for university geology courses. However, non-geologists accompanied by an expert will also be able to appreciate the scientific content of the panels.

Stop Description

The geological itinerary in the Sasso di Castalda area is summarised below. The position of each stop is provided using decimal degrees and the WGS84 ellipsoid.

Fig. 6 Examples of panels (a) and covered niches (b) developed for the Sasso di Castalda geological itinerary



- Stop 1 (40.488437, 15.677442) introduces visitors to the geology of the Sasso di Castalda territory. The panel includes a palaeogeographic scheme illustrating the pre- and post-orogenic setting of the Southern Apennine area, a detailed geological map with cross-sections and a synthetic stratigraphic column showing the Lagonegro Basin succession, which outcrops in the Sasso di Castalda area.
- Stop 2 (40.488893, 15.677563) illustrates the general sedimentological and stratigraphical characters of the Early–Middle Triassic Monte Facito Formation. This represents the base of the Lagonegro II unit and is characterized by shallow to deep-water rocks indicating the birth of the Lagonegro Basin. Interestingly, this formation was first described at Monte Facito, which is only about 3 km south-east of the Sasso di Castalda village (Figs. 1 and 2). In addition, Stop 2 provides a short description of the Monte Facito shallow-water deposits, which comprise quartz-rich sandstones with wave ripples and algae-bearing neritic limestones which are interpreted as carbonate build-ups. One of the best outcrops of the Monte Facito Formation is shown in Fig. 7a, where several levels of neritic limestones are separated by red claystones.
- Stop 3 (40.488906, 15.678106) describes the subsidence phase, which occurred at the end of the Ladinian, when clayey and radiolaritic sedimentation took place during the drowning of Ladinian build-ups. The display niches contain samples of sandstone with wave ripples and a brachiopod-rich limestone derived from the carbonate platform facies of Monte Facito Formation.
- Stop 4 (40.489365, 15.678070) illustrates the Late Triassic Calcarei con Selce Formation, with particular emphasis on a sample of cherty limestone that is the typical lithotype. The Calcarei con Selce Formation consists of white well-stratified deep-water limestones forming a great part of the La Manca gorge (Fig. 7b). The sedimentological characters indicate a significant deepening of the Lagonegro Basin bathymetry, which has been estimated as around 1,000–2,000 m, and a considerable increase in the carbonate supply.
- Stop 5 (40.490168, 15.677601) illustrates the upper member of the Scisti Silicei Formation (Late Triassic–Jurassic). The description of the lower member is included in the panel for Stop 12. The upper part of the Scisti Silicei Formation consists of thin, regularly bedded, red, yellow or green-coloured radiolarites. Figure 7c shows a radiolarite from the panel of Stop 5. The complete absence of limestone beds indicates sedimentation beneath the carbonate compensation depth (CCD), and the depth of the Lagonegro Basin has consequently been estimated at around 3,000 m during Jurassic times. A sample of red-coloured radiolarite is the lithotype chosen to represent the formation in the niche.
- Stop 6 (40.489998, 15.676703) illustrates the main characteristics of the Galestri Formation (Late Jurassic–Early Cretaceous; Fig. 7d). In this case, the representative sample is a marly limestone showing the typical “Pietra Paesina” character, derived from presence of an obvious fracture network. The formation was deposited in a deep basin (estimated around 2,000–3,000 m) with argillaceous sedimentation episodically interrupted by fine-grained carbonate turbidite flows.
- Stop 7 (40.490157, 15.676618) describes a small outcrop located at the base of the old La Manca houses, where the Scisti Silicei beds are strongly affected by contractional deformation (Fig. 8a, b). The outcrop provides an opportunity to introduce some basic concepts regarding folds and thrusts. In particular, it is possible to observe at the outcrop-scale well-developed fault propagation folds. These structures are connected to the development of the main La Manca Fold that formed during the contractional evolution of the Apennine chain.

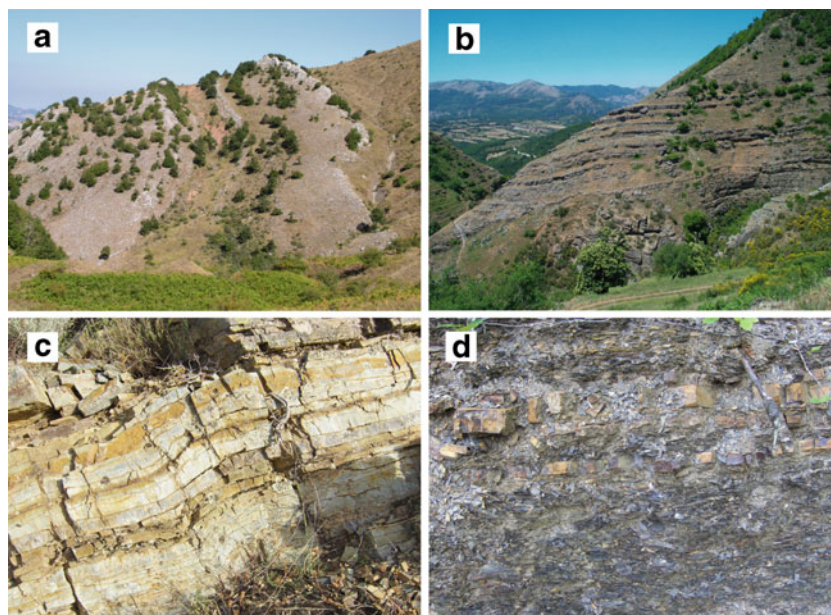


Fig. 7 Lithological characters of the formations outcropping in the Sasso di Castalda area. **a** Monte Facito Formation (Stops 2 and 3): panoramic view of a shallow-water Monte Facito Formation-type succession located some kilometres NW of Sasso di Castalda village. The outcrop shows alternating bioclastic limestone and clays, representing the biogenic and terrigenous members of Monte Facito Formation, respectively. **b** Calcari con Selce Formation (Stop 4): well-bedded

cherty limestones cropping out in panorama view in the right side of the La Manca gorge. **c** Scisti Silicei Formation (Stop 5): close-up view of well-bedded cherts cropping in the right side of the La Manca gorge. **d** Galestri Formation (Stop 6): close-up view of a typical marl–shale alternation, characteristic of the formation, cropping-out in the southwestern flank of the La Manca Fold

Stop 8 (40.490978, 15.676795) is located close to Arenatra stream, where an obvious right-lateral transtensional fault (the Arenatra Fault) offsets the stratigraphic boundary between the Calcari con Selce and Scisti Silicei formations (Fig. 9a). On the fault plane, it possible to observe well-developed kinematic indicators such as slickensides and fibrous calcite steps. In addition, limestone beds of the Calcari con Selce Formation, located in the footwall, are dragged consistently with the fault kinematics. In the Southern Apennines, transtensional faults are generally related to a post-orogenic extensional stage which occurred during the Pleistocene. These faults crosscut all earlier contractional structures, and a preliminary introduction to faults and associated structures is, therefore, provided to visitors at Stop 8.

Stop 9 (40.490108, 15.676359) is located on one of the numerous terraces which face the right slope of the La Manca gorge. Here, the western limb of the kilometre-scale box fold—identified as the La Manca Fold, which affects the multilayer sequence of the Calcari con Selce and Scisti Silicei formations—can be observed in a panoramic view (Fig. 9b). The fold shows a marked angular hinge with straight limbs dipping 10° and 70° to the SW, respectively. Some small-scale features within the structure, such as parasitic folds and calcite steps formed by flexural slip phenomena, are illustrated by photographs and drawings in the panel. These structures can be seen by walking from La Manca to the Madonna delle Grazie chapel (Fig. 9b). Outside the chapel, it is possible to observe the gradual

Fig. 8 Structure observed at the base of La Manca houses (Stop 7): **a** meso-scale-sized folds and thrusts; **b** interpretative line drawing

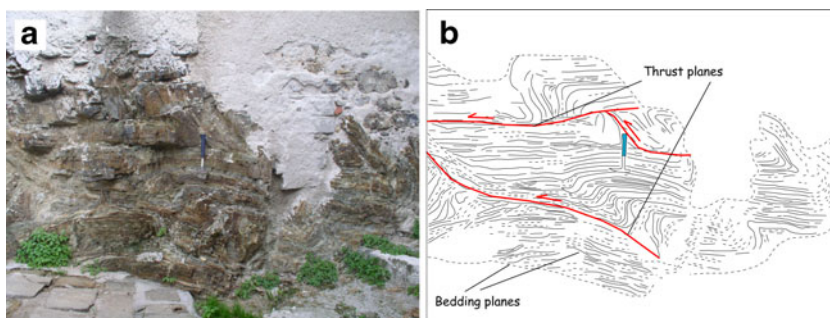
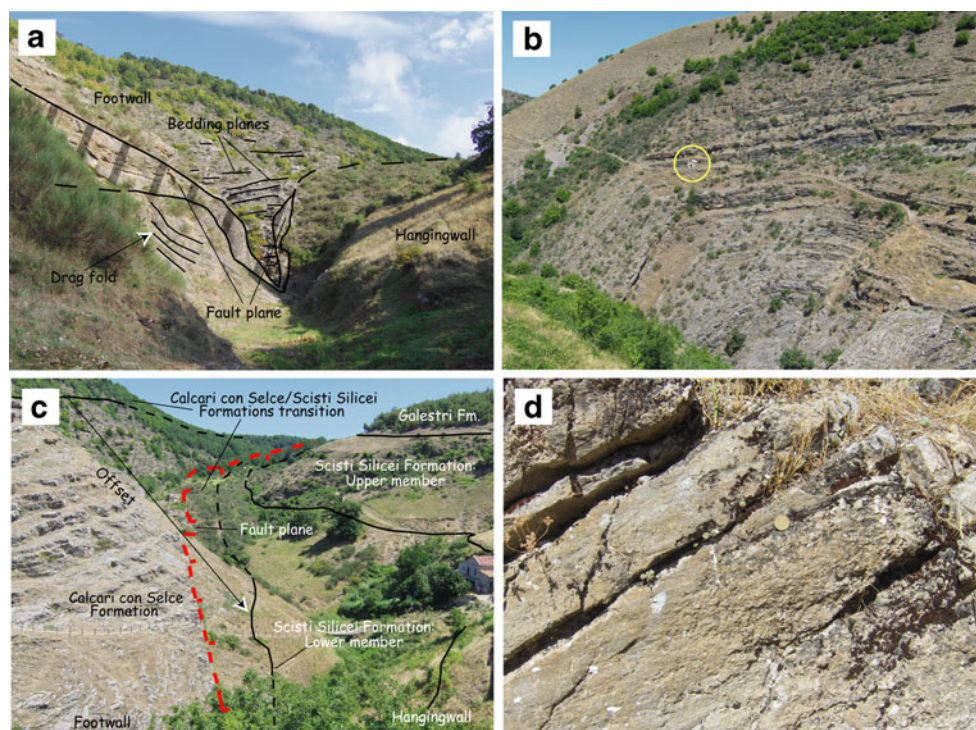


Fig. 9 **a** Panoramic view of the Arenatra Fault (Stop 8). The main characteristics are outlined. **b** Panoramic view of La Manca Fold (Stop 9). The Madonna delle Grazie chapel (*in the circle*) is used as scale. **c** Arenatra Fault viewed along the strike (Stop 10). Note the strong morphological contrast between the more competent Calcari con Selce limestones in the footwall and the Scisti Silicei and Galestri lithologies at the hanging wall. **d** Close-up view of the Arenatra Fault (Stop 11), outcropping along the Sasso di Castalda itinerary, showing well-developed slickensides



transition from the Calcari con Selce to Scisti Silicei formations.

- Stop 10 (40.490101, 15.675917) offers a spectacular cross-sectional view of the Arenatra Fault plane (see Stop 8) showing the Calcari con Selce Formation in the footwall (Fig. 9c). The Scisti Silicei Formation in the hanging wall is downthrown for about 100 m.
- Stop 11 (40.490017, 15.675659) shows a detail of the Arenatra Fault plane which outcrops in the older part of the Sasso di Castalda village. The steep fault plane, crosscutting chert and limestones of the Calcari con Selce transitional interval, shows different generations of slickensides, with pitch angles varying from 25° to 30°. In addition, a well-developed fault breccia can be observed on the slip surface (Fig. 9d).
- Stop 12 (40.489852, 15.675089), located almost at the top of the “Il Castello” cliff, reveals the lower portion of the Scisti Silicei Formation. This part of the stratigraphic succession is very unusual and differs

markedly in lithology when compared to the upper part of the formation. The succession, exposed along the stairways leading to the tower, comprises purple and red claystones alternating with massive turbiditic limestones (Fig. 10a). The latter contains resedimented sponges and algae deriving from the Campano–Lucana Platform (Fig. 10b).

- Stop 13 (40.489678, 15.675141) demonstrates a parasitic fold, with nearly isoclinal geometry, developed within the lower part of the Scisti Silicei Formation (Fig. 11a, b). The panel outlines the main features of the fold and the pervasive cleavage which mainly affects the marly layers.
- Stop 14 (40.489282, 15.674897) illustrates a detail of the steep south-western limb of the La Manca Fold, where gentle metre-scale folds are developed (Fig. 12).
- Stop 15 (40.489130, 15.677264) consists of a panel summarizing the main stratigraphic and structural points illustrated by the itinerary. Structures

Fig. 10 Lower member of the Scisti Silicei Formation at the “Il Castello” cliff (Stop 12): **a** particular of the lower member of the Scisti Silicei Formation showing a lens-shaped calcar-enite body; **b** detail of calcar-enites (*in thin section*) showing bioclastic clasts represented by algae

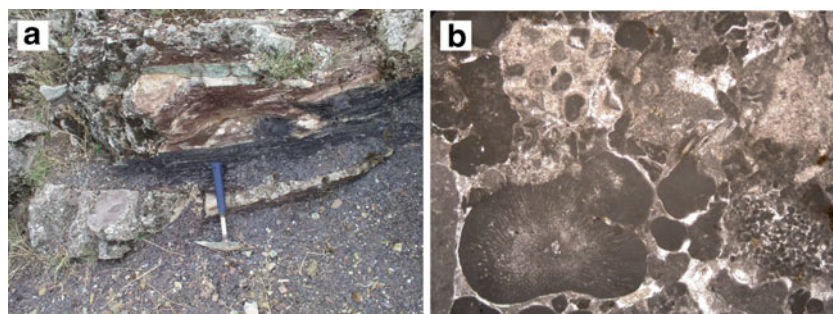
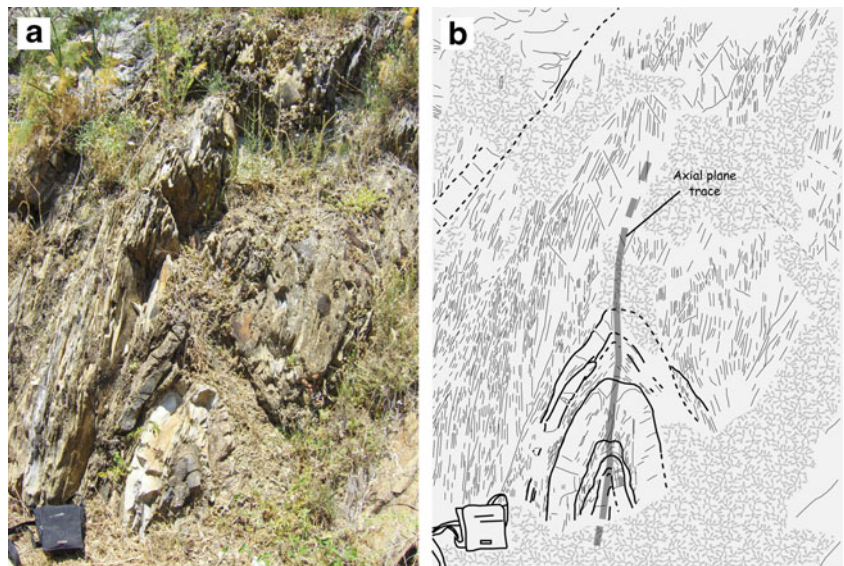


Fig. 11 Folding at the base of the “Il Castello” cliff (Stop 13): **a** isoclinal fold developed in the lower member of the Scisti Silicei Formation; **b** interpretative line drawing



observed in Stops 7–14 are put in a representative geological cross-section of the Sasso di Castalda area, hence placing the outcrop-scale observation within a larger-scale context.

Discussion and Conclusions

In the Sasso di Castalda area, significant and well-exposed geological features are concentrated in a relatively small area, allowing both detailed and panoramic view observation. The scientific value of the outcrops is twofold. Firstly, representative exposures of a Late Triassic–Early Jurassic succession allows a detailed study of the Mesozoic evolution of the Lagonegro Basin, as has been described in various scientific papers (Bertinelli et al. 2005 and references therein). Secondly,



Fig. 12 Folding at the base of the “Il Castello” cliff (Stop 14): meso-scale gentle folds developed in the jasperised cherts of the upper member of the Scisti Silicei Formation

crosscutting relationships between tectonic structures can be used to document the main tectonic stages which characterise the evolution of the Southern Apennines (Tavarnelli and Prosser, 2003). These factors together indicate that the representative outcrops in the Sasso di Castalda area also have a national relevance.

The itinerary has been established in order to spread knowledge of the geological heritage of the Southern Apennines. Until now, however, geoconservation procedures have only partially been established in the Sasso di Castalda area. The development of the geological itinerary, however, is very useful as it disseminates awareness of the scientific value of the Sasso di Castalda outcrops and can therefore help promote suitable conservation actions.

The geological itinerary offers a unique opportunity to make a journey into the evolutionary history of the Southern Apennine thrust-belt. This evolution can be subdivided into three stages, from 250 Ma during the opening and the closure of the Lagonegro Basin to later interactions between the African and European plates.

The first stage is demonstrated by a deepening upward succession due to subsidence processes produced by continental rifting and drifting. This evolution has been reconstructed from rocks exposed in the Sasso di Castalda area. In more detail, deposits of the Monte Facito Formation record shallow-water conditions during the first continental rifting stages. At this time (Early to Mid Triassic), marine deposits are mainly represented by isolated algal-bearing carbonate build-ups and by wave and storm-influenced clastic sediments. The progressive crustal thinning led to marked subsidence, which is recorded in the Lagonegro Basin by the deposition of the upper part of the Monte Facito Formation and, subsequently, by the deposition of the Calcari con Selce, Scisti Silicei and Galestri formations.

The second stage started at the end of the Oligocene, when contractional deformation, resulting from the inversion of the relative motion between the African and European plates, led to the construction of the Apennine mountain belt. During this time, folds and thrusts developed extensively, affecting units of the Lagonegro Basin. Contractional structures linked to the syn-orogenic stage are spectacularly exposed within the La Manca gorge, a deeply incised valley located at the hinge of La Manca box fold. The third stage of the area's evolution is related to the development of strike slip faults, indicating the late- to post-orogenic evolution of the Apennine chain during Pliocene to Pleistocene times. These faults clearly crosscut the older contractional structures, as displayed by outcrops along the La Manca gorge.

The development of the geological itinerary of Sasso di Castalda has been strongly supported by the local town administration, which contributed to the costs and provided safety works at some of the key outcrops. In addition, the administration's council is committed to the maintenance of the roads and buildings along the itinerary. The scientific interest of the area draws students and researchers from both Italian and foreign universities. Since its establishment in 2009, the geological itinerary has been visited by more than 1,500 people a year—as estimated by the local tourism association. Extensive exposures permit the geometry of simple geological structures, such as faults and folds, to be demonstrated and the relationships between them described. Observations can be performed at different scales, outlining the significance of small-scale structures in a larger-scale geological context. For these reasons, this itinerary can be used for teaching at various school levels, as well as for university courses. Stops along the itinerary include a preliminary introductory panel and a final summary that serve to connect the separate observations into a single story. For this reason, even though the number of stops is relatively large, walking along the itinerary progressively develops an understanding of the overall geological setting.

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