Journal of Maps

ISSN: (Print) 1744-5647 (Online) Journal homepage: https://www.tandfonline.com/loi/tjom20

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To cite this article: Francesco Bucci, Rocco Novellino, Paola Guglielmi & Enrico Tavarnelli (2020) Growth and dissection of a fold and thrust belt: the geological record of the High Agri Valley, Italy, Journal of Maps, 16:2, 245-256, DOI: 10.1080/17445647.2020.1737254

To link to this article: https://doi.org/10.1080/17445647.2020.1737254

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JOURNAL OF MAPS
2020, VOL. 16, NO. 2, 245–256
https://doi.org/10.1080/17445647.2020.1737254

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Growth and dissection of a fold and thrust belt: the geological record of the High Agri Valley, Italy

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ABSTRACT

We present a 130 km^2 wide geological map for the NE side of the fault-bounded High Agri Valley Southern Italy, that formed in the Quaternary in response to extensional tectonics dissecting the folds and thrusts of the Lucanian Apennine. To prepare the map, at 1:25,000 scale, we integrated information obtained through field surveys and the review of pre-existing geological data. Our work describes a number of significant map-scale structures, which can be related to well-constrained tectonic episodes. The new geological map provides important constraints that can be used to distinguish ancient structures from those that were active during the Quaternary, allowing a more detailed reconstruction of the processes that operate during the development of a post-orogenic trough. We expect that the new map will be used for different types of geological investigations, including studies of inversion tectonics, active tectonics, geosite mapping, 3D modelling of geological structures.

ARTICLE HISTORY
Received 27 September 2019
Revised 24 February 2020
Accepted 27 February 2020

KEYWORDS
Geology; field mapping; extension; Quaternary; tectonics; Apennines; Italy

1. Introduction

We present a geological map of the NE margin of the High Agri Valley, Southern Apennine, Italy. To prepare the map we used a traditional approach to geological mapping that exploits extensive field survey, combined with more detailed outcrop-scale collection of structural data, stratigraphic log compilation and rock sampling, and the critical review of published surface (ISPRA, in press-a, in press-b) and sub-surface (Menardi-Noguera & Rea, 2000) geological information, including active tectonic studies (Ferranti et al., 2007). The approach is commonly used for mapping geological structures and for the production of geological and structural maps (Bucci et al., 2016; Vignaroli et al., 2019). Here, we extend the use of this approach to document the double tectonic inversion (positive and negative) of a previously rifted continental margin (Di Francesco et al., 2010; Tavarnelli et al., 2003; Tavarnelli & Prosser, 2003), and to characterize the deformation history of a seismically active post-orogenic trough (Mancini et al., 2019; Mirabella et al., 2018; Tavarnelli & Pasqui, 1998, 2000).

2. Geological setting

The Southern Apennine is a fold and thrust belt, mainly consisting of imbricates of Mesozoic-Cenozoic deep-basin and carbonate-platform rocks that were deposited adjacent to, and on the western continental margin of Adria, a promontory of North Africa (Channel et al., 1979). Differentiation of the palaeogeographical domains was controlled by syn-sedimentary, pre-orogenic normal faults developed during the rifting stage that led to the Mesozoic Tethys Ocean and to drifting of the Adria and European continental margins. From Eocene time onwards (Knott, 1994) the palaeogeographical domains experienced contraction related to the closure of the Tethys Ocean and to the collision of the European and Adria margins, with development and imbrication of the main tectono-stratigraphic units. Mesozoic, pre-orogenic normal faults were overprinted by thrusts and related folds during this episode of positive tectonic inversion. Stacking of the tectonic pile continued throughout the Early Miocene – Pleistocene time interval and progressively migrated towards the Apulian foreland of Southern Italy.

The following groups of tectono-stratigraphic units can be distinguished in the Southern Apennine chain. Each unit is separated from the underlying and overlying ones by first-order thrust surfaces. Their description starts from the most internal units that occupy the highest position in the tectonic pile: (i) Liguride Units, derived from the deformation of the Tethyan oceanic domain; (ii) Sicilide Unit, derived from a more external basin domain; (iii) Units consisting of thick successions of Triassic-to-Miocene platform carbonates and

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Miocene siliciclastic flysch, and 'transitional' units mainly consisting of slope-to-basin re-sedimented carbonates; (iv) units derived from deep basins developed onto an attenuated continental crust, including the Mesozoic sequences of the Lagonegro Basin and the Tertiary sections of the same basin detached and displaced eastward; (v) a buried thrust system composed of shallow-water and subordinate deeper-water Mesozoic-Tertiary carbonates, that are stratigraphically covered by Pliocene terrigenous deposits, and tectonically overlain by a thick pile of E-NE-verging rootless nappes derived from basin and platform domains (Patacca & Scandone, 2007 and references therein).

The emplacement of these main tectono-stratigraphic units was accompanied by the deposition of syn-orogenic litho-stratigraphic units within thrust-top and foredeep basins during the Oligocene-Miocene (Albidona Formation, Bonardi et al., 1988) and Miocene time (Gorgoglione Formation, Butler & Tavarnelli, 2006). Eastward, active contractional deformation affected Plio-Pleistocene deposits within a number of minor basins located in correspondence of the eastward-migrating Apennine front.

Since the Pliocene, contractional deformation in the eastern sector was accompanied by extensional tectonics in the western and axial part of the orogen. Pliocene low-angle normal faults (Mazzoli et al., 2014) early Pleistocene left-oblique transtensional faults (Hippolyte et al., 1994) and Quaternary – to Holocene high-angle normal faults produced the progressive fragmentation of the fold-and-thrust architecture, leading to the present, highly complex structural configuration.

3. Study area

The study area extends for about 130 km² in Western Basilicata, Italy (Figure 1A). Elevation in the area ranges from 600 m (Villa d'Agri, valley bottom) to 1824m (Top of Monte Volturino) with a maximum relative relief approaching 1000 m along the western slopes of the Monte Volturino and Monte di Viggiano (Figure 1) summits. The Agri river drains the area toward S-SE. The study area comprises part of the NE margin of the fault-bounded, intermountain High Agri Valley (Figure 1B) that formed during the Quaternary under transtensional/extensional tectonic regime. The study area is characterized by remarkable outcrops of dominantly marine sediments pertaining to: i) the Lagonegro stratigraphic succession (Figure 1; L1, L2), Triassic to Oligocene in age (Scandone, 1972); ii) the Campania-Lucania carbonate Platform (Figure 1; AP), Triassic to Cretaceous in age (Palladino et al., 2008); iii) the *incertae sedis* Argille Variegate Group (Figure 1; TL), Cretaceous to Oligocene in age, interpreted as the Cretaceous to Cenozoic prosecution of the Lagonegro succession within the L1 tectonostratigraphic unit (Mattioni et al., 2006; Pescatore et al., 1999); iv) the Ligurian tectonostratigraphic Unit, here represented by the Torrente Cavolo formation (Figure 1; LG), Oligocene to early Miocene in age (Carbone et al., 1991); v) The Gorgoglione flysch, Miocene in age (Pescatore, 1978), above the Argille Variegate Group (TL) (Figure 1). Figure 2 synthesizes the tectonostratigraphic relationships within the pre-quaternary rock assemblages. At the base of the relief, quaternary slope breccias consisting of coarse-grained carbonate fragments, extensively crop out. In the valley and at the outlet of the river courses, finer-grained quaternary sediments, deposited in lacustrine and alluvial environments, are exposed (Figure 1, Ls, Hd, Sd deposits). The study area is characterized by remarkable outcrops of dominantly NW-SE trending high angle fault segments with left-oblique transtensional kinematics, which control the staircase profile of the ridge bounding eastward the High Agri Valley graben. The extensional tectonics leading to the formation and evolution of the High Agri Valley graben is still active in the area (Giano et al., 2000), and is responsible for the occurrence of strong historical earthquakes (Burrato & Valensise, 2008).

4. Methods

The geological map (main map) is the result of a field-based survey. The geological survey was carried out at the 1:10,000 scale and then compiled at the 1:25,000 scale (Carta Topografica d'Italia – Serie 25 – IGM), in order to complement, and to render it consistent with, a previously published geological map that covers the central portion of the study area (Bucci et al., 2012), whose informative content is integrated in the present map and study.

To compile the geological map, we integrated stratigraphic and structural information. The attitude of bedding was recorded at all investigated sites. Systematic analysis of tectonic structures was carried out to decipher the succession of deformation events that resulted in the present-day regional scale (folds, thrusts, faults) and mesoscopic (faults, joints, veins, pressure solution seams) structures. Evidence for Quaternary faulting was outlined and analysed using integrated structural and geomorphic criteria. Cemented talus breccia and crudely bedded loose debris outcropping at the base of the slopes were surveyed to detect evidence for possible recent faulting.

We collected a total of 1559 geological and structural parameters measured. Point measurements include: (i) 884 strike and dip measurements of bedding; (ii) 227 strike and dip measurements of fault surfaces; (iii) 251 trend and plunge measurements of fault striae; (iv) 153 strike measurements of fractures, veins and tension gashes; and (v) 44 trend and plunge measurements of fold axes. Due to the strong clustering

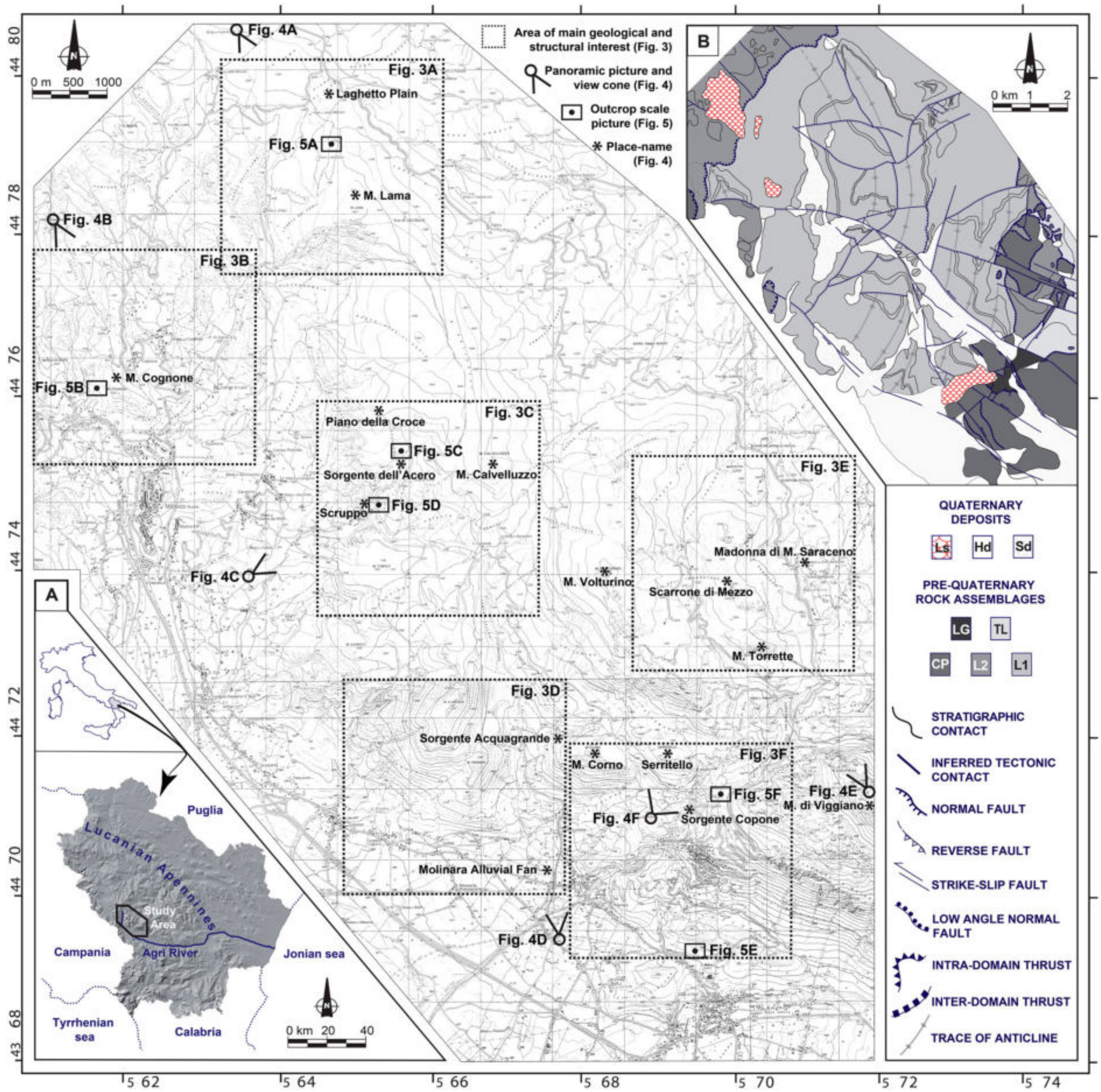

Figure 1. Topographic map of the study area. The position of the details illustrated in Figure 3 is indicated. A – Geographic location of the study area in the framework of the Lucanian Apennines, southern Italy. B – Tectonic sketch map of the study area. CP, Campania-Lucania Platform unit; Hd, Holocene deposit; Ls, Landslide deposit; L1, Lagonegro I unit; L2, Lagonegro II unit; LG, Ligurian unit; Sd, Slope deposit; TL, Cretaceous to Cenozoic Lagonegro I sequence.

of data points, we report in the map only the most significant of them (281 points).

5. Geological Map

The geological map shows: (a) three continental lithological units, early to Upper Pleistocene in age; (b) the Gorgoglione flysch, lower to middle Miocene in age; (c) the Ligurian tectonostratographic Unit, Oligocene to early Miocene in age; (d) the *incertae sedis* Argille Variegate Group, Cretaceous to Oligocene in age; (e) three informal lithostratigraphic units belonging to the Campania-Lucania Carbonate Platform stratigraphic succession, Triassic to Upper Cretaceous in age; (f) Mesozoic to Cenozoic tectonostratigraphic successions belonging to the pelagic Lagonegro Basin Domain, indicated in the geological literature respectively as Lagonegro I Unit and Lagonegro II Units. Six formalized formations are recognized within the Lagonegro Units: i) the Monte Facito Formation (Lower-Middle Triassic); ii) the Calcari con selce formation (Upper Triassic), iii) the Scisti Silicei formation, (Jurassic); iv) the Flysch Galestrino formation (Lower Cretaceous); v) the Flysch Rosso formation (Upper Cretaceous-Oligocene); the Argilliti del Torrente Serrapotamo formation (Oligocene) (Figure 2). A number of differences makes it possible to distinguish the Lagonegro I from the Lagonegro II tectonostratigraphic Units. These include the following: i) the Monte Facito Formation is lacking at the base of the Lagonegro I Unit

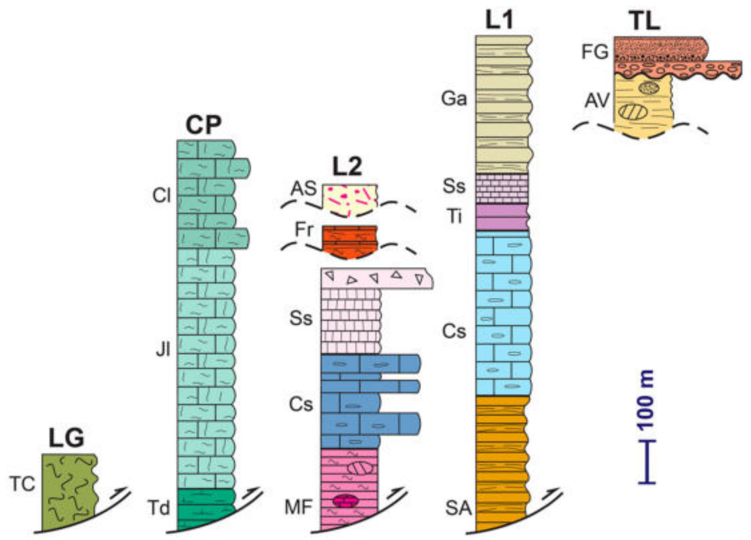

Figure 2. Stratigraphic sections from the study area (after Bucci et al., 2012, modified). AV, Argille Variegate group (late Cretaceous to Oligocene); AS, Argilliti del Torrente Serrapotamo (Oligocene); Cl, Cretaceous limestone; Cs, Calcari Con Selce Formation (Late Triassic); Fr, Flysch rosso formations (late Cretaceous to Oligocene); FG, Flysch di Gorgoglione (middle Miocene); Ga, Flysch Galestrino (Cretaceous); Jl, Jurassic limestone; MF, Monte Facito Formation (Middle to Late Triassic); SA, Sorgente dell'Acero formation (Carnian); Ss, Scisti silicei (Jurassic); TC, Torrente Cavolo formation; Td, Triassic dolostone; Ti, Intervallo di transizione (late Norian to Rhaetian).

and it is replaced by a marly/calcareous informal lithostratigraphic unit, here named Sorgente dell'Acero formation, according to Scandone, 1967; ii) the Calcari con Selce and Scisti Silicei formations of the Lagonegro I Unit are separated by an informal lithostratigraphic unit, made up of alternating cherty limestone, radiolarites and red shale, here named 'Intervallo di transizione', according to Amodeo et al., 1993; iii) the Flysch Rosso and the Argilliti del Torrente Serrapotamo formations are lacking at the top of the Lagonegro I Unit, where the Flysch Galestrino formation closes upward the Mesozoic succession (Figure 2). For a detailed description of the stratigraphy of the area, the reader is referred to Bucci et al., 2012 (and reference therein).

The main features identified in the study area are (from oldest to youngest) (Figure 1 for location): i) the relationships between pre-orogenic and sin-orogenic structures (Figure 3A); ii) the imbrication of the Lagonegro I and II tectonic Units (Figures 3A, B); iii) the regional thrusting of the Campania-Lucania Unit on to the Lagonegro Units (Figure 3B); iv) major anticlines (Figures 3A, B, C, D, E); v) the Mt. Lama – Mt. Calvelluzzo Pop-Up structure (Figure 3C); vi) the occurrence of isolated external slices ('klippen') of carbonate platform rocks derived from the Campania-Lucania Unit (Figure 3E); vii) several post-orogenic fault systems and their cross-cutting and overprinting relationships (Figure 3F).

i The main observations related to the role of pre-orogenic extensional tectonics were carried out along the Mt. Lama anticline (Figure 3A and Figure 4A). The effects of pre-orogenic extension are particularly clear at the northern termination of the Monte Lama anticline, a major, map-scale fold involving the sedimentary succession of the Lagonegro I Unit. In the eastern limb of the anticline the Jurassic Scisti Silicei are thin (40–50 metres), whereas in the western limb the same formation is much thicker (100–150 metres) and contain abundant slumping structures (Figure 5A), an indication of intense seafloor mobility during deposition. These thickness variation in the Jurassic Scisti Silicei are controlled by a major, Km-scale syn-sedimentary, pre-orogenic normal fault (Figure 3A). The fault is sealed by the Cretaceous post-rift Flysch Galestrino (Figure 3A). These relationships constrain the activity of the mapped normal fault to Jurassic time. During the positive tectonic inversion stage, this structure controlled the development of the Monte Lama thrust-ramp anticline, as revealed by the sub parallel attitude of the Mt. Lama fold with respect to the Jurassic fault (main map). In addition, at the northern termination of the Mt. Lama anticline, a continuous stratigraphic contact can be observed between the Scisti Silicei formation and the Flysch Galestrino, which seals the Jurassic normal fault. Thus, no significant evidence for reactivation of the Jurassic normal fault during the subsequent tertiary thrusting events and the quaternary transtensional deformations is documented. Along the western limb of the M. Lama anticline no evidence for active or recent tectonic features parallel to the Jurassic fault, including tectonic scarps and triangular facets on a fault scarp (Benedetti et al., 1998; Papanikolaou & Roberts, 2007), was found. The map pattern

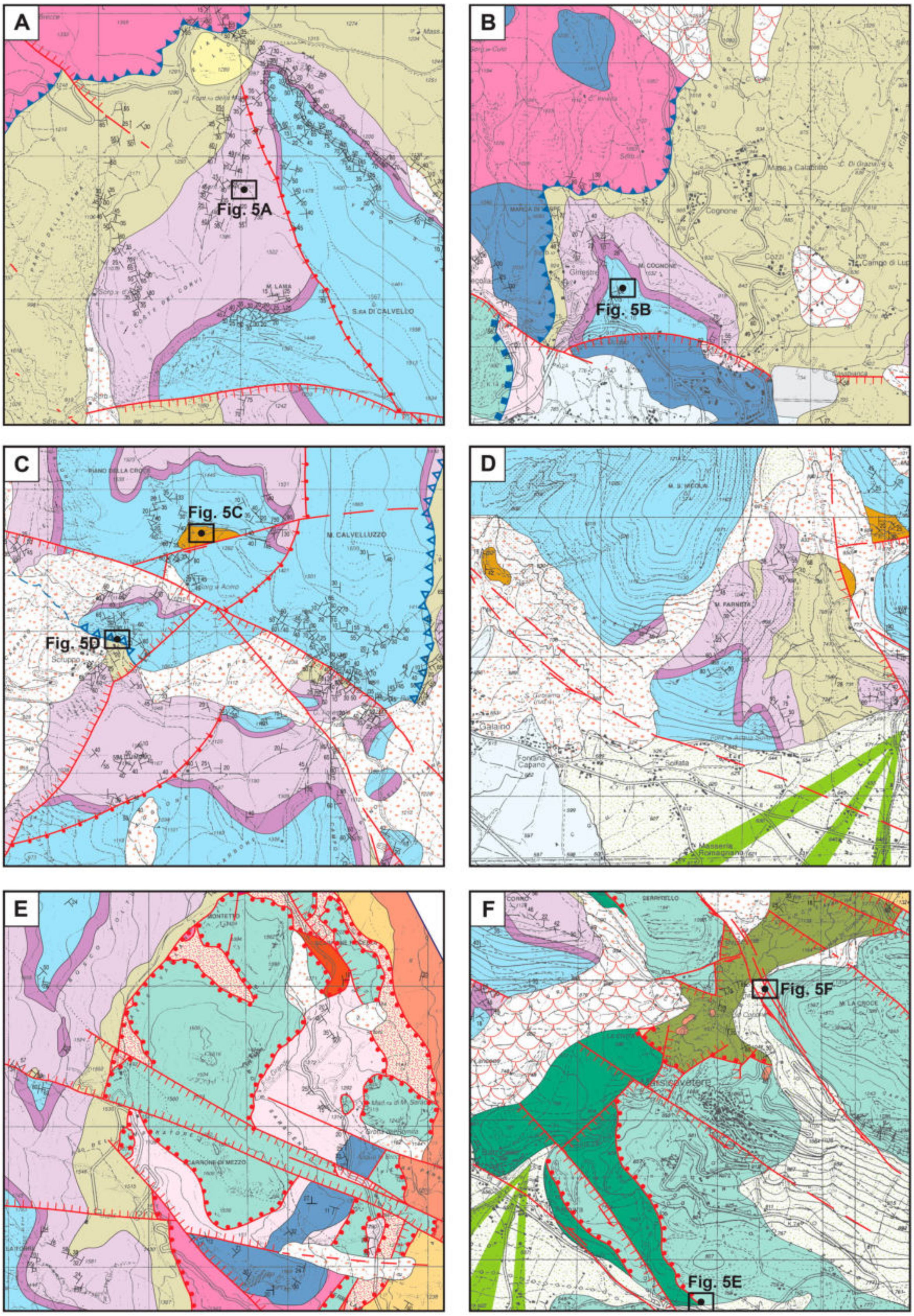

Figure 3. Details of the general map, object of the present study, showing the relationships amongst rocks belonging to different tectonic units and those amongst structures that affect the various lithostratigraphic units cropping out in the study area. See Figure 2 for the colours legend. A – The northern termination of the NNW-plunging Mt. Lama Anticline (see text for explanation); The location of structures reproduced in Figure 5A is indicated. B – The northern termination of the NNW-plunging Mt. Cugnone Anticline. The location of structures reproduced in Figure 5B is indicated. C – Detail of structures cropping out in the Sorgente dell'Acero area. The position of structures illustrated in Figure 5C and D is indicated. D – Detail of the structures cropping out near Mt. S. Nicola and Mt. Farneta, SW of Mt. Volturino. Outcrops of Sorgente dell'Acero formation (light brown polygons) are mapped in the Sorgente Acquagrande (NE corner) and Galaino (NW corner) sites. E – Detail of structures cropping out at Scarrone di Mezzo and Mt. Torrette, SE of Mt. Volturino. F – Detail of structures cropping out in the vicinities of Marsico Vetere. The position of structures illustrated in Figure 5E and F is indicated.

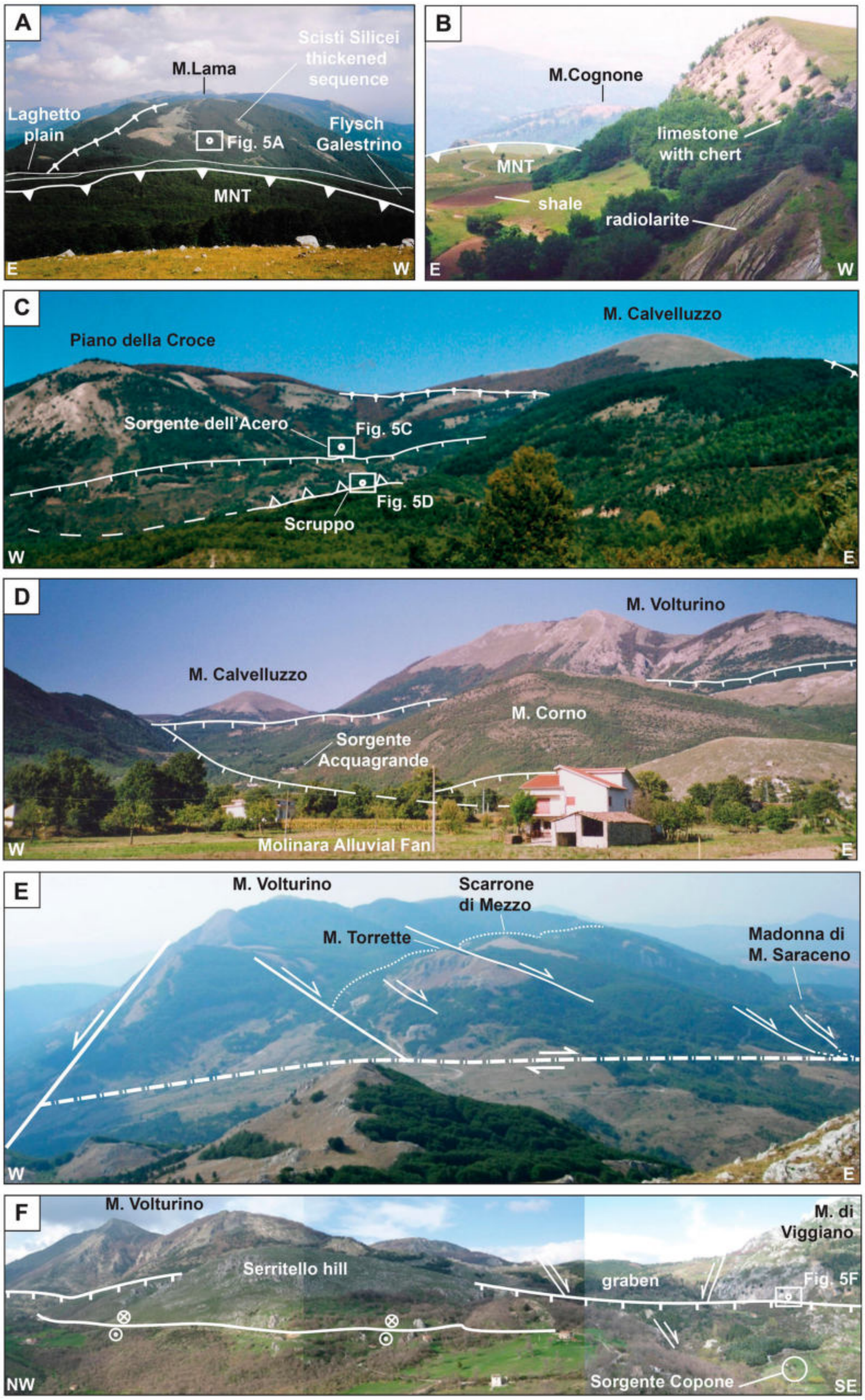

Figure 4. Panoramic views of areas where the overprinting relationships amongst structures produced at different times are particularly clear. A – Panoramic view of Mt. Lama (seen from N to S). The location of structures reproduced in Figure 5A is indicated. B – Panoramic view of Mt. Cugnone (seen from N to S). C – Panoramic view of the Piano della Croce-Mt. Calvelluzzo area (seen from S to N). The location of structures reproduced in Figure 5C and D is indicated. D – Panoramic view of the Mt. Calvelluzzo-Mt. Volturino area (seen from S to N). The location of Sorgente Acquagrande and of the Molinara alluvial fan is indicated. E – Panoramic view of the Mt. Volturino-Madonna di Mt. Saraceno area (seen from S to N). The location of Mt. Torrette and of Scarrone di Mezzo is indicated. F – Panoramic view of the Mt. Volturino-Mt. di Viggiano area (seen from SW to NE). The location of the Serritello Hill and of Sorgente Copone is indicated.

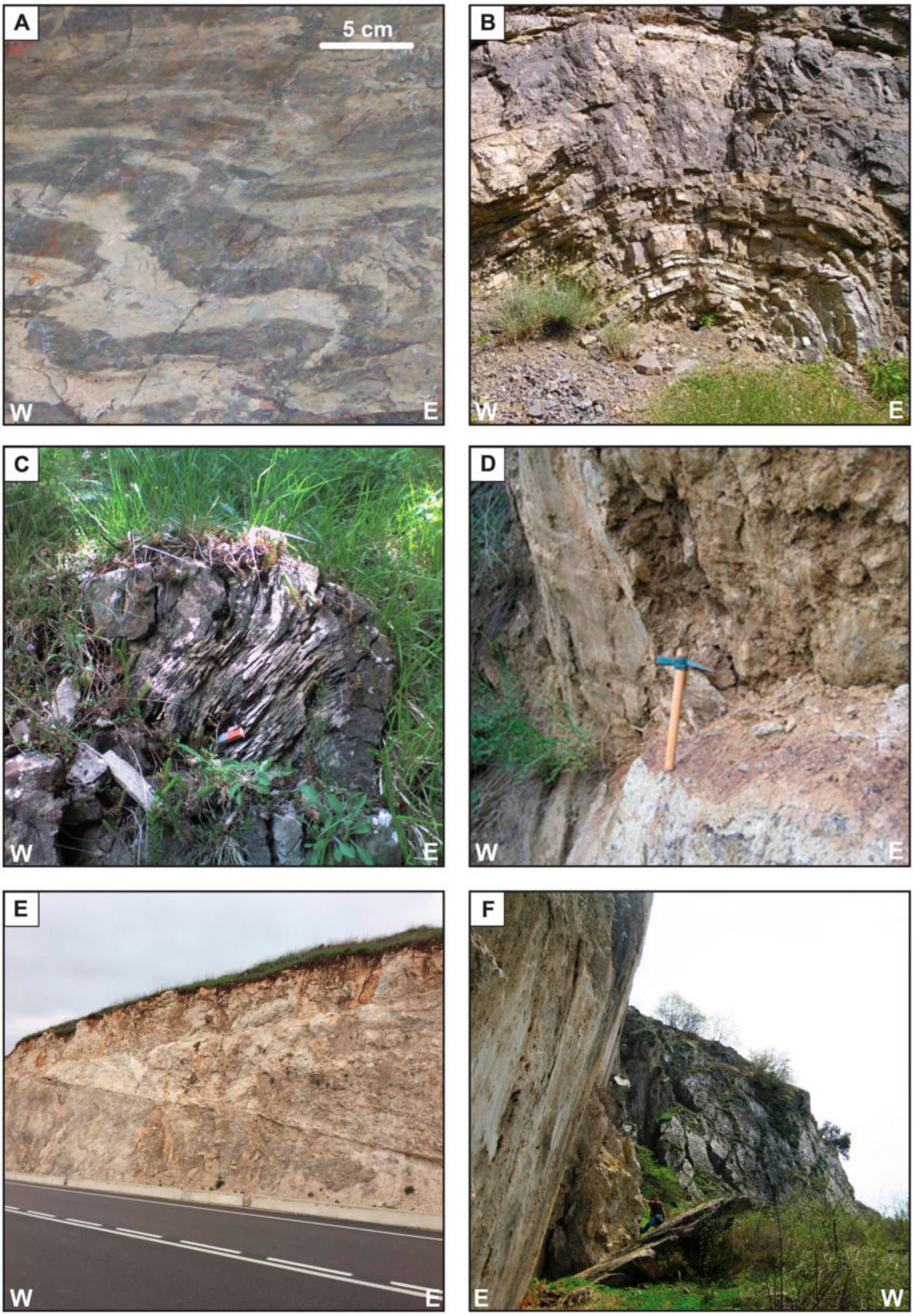

Figure 5. Mesoscopic, outcrop-scale structures cropping out in the study area. A – Asymmetric slumps in the Jurassic Scisti Silicei Fm. near Mt. Lama (Location in Figures 1, 3A, 4A). B – Concentric anticline affecting limestone beds of the Triassic Calcari con Selce Fm. near Mt. Cugnone (Location in Figures 1, 3B, 4B). C – Tight folds associated with well developed axial planar cleavage in the core of the Mt. Lama – Mt. Calvelluzzo anticline (Location in Figures 1, 3C, 4C). D – Steep reverse fault cutting the base of the western slope of the Mt. Lama ridge (Location in Figures 1, 3C). E – Low-angle normal fault affecting the carbonate rocks of the Campania-Lucania Platform Unit (Location in Figures 1, 3F). F – High-angle, oblique-to-strike slip fault with left-lateral kinematics (Location in Figures 1, 3F, 5F).

further rules out roughly N–S trending active tectonic structures, an evidence that is consistent with the Quaternary fault array, which displays a main NW–SE trend locally associated with W-E oriented fault segments (Figure 3A).

ii West of the Mt. Lama anticline, the imbrication of the Lagonegro Units was extensively mapped. The position of the thrust contact that separates the Lagonegro II Unit from the underlying Lagonegro I Unit is poorly constrained because the Monte Facito Formation, in the hanging-wall and the Flysch Galestrino, in the footwall, are both shaly and subject to landslides (see Main Map and Figures 3A, B). In the map, the thrust contact was defined in the position where it separates the strongly tectonized hanging-wall block and the thrust zone, from the less intensely deformed layered footwall block. Several post-orogenic faults cut across the thrust assemblage. Due to the lack of clear outcrops, the effects of these post-orogenic faults on the thrust contact are revealed only from the map pattern. In spite of these limitations, the thrust contact was recognized and mapped for several kilometres in the NW corner of the study area. Based on the map pattern, the Marsico Nuovo Thrust (MNT) strikes NNE, but shows a marked EW bend immediately north of the Monte Lama anticline and of the Monte Cugnone anticline (Figures 3A, B). The thrust surface is poorly exposed, but its map pattern suggests that the MNT is gently folded (Figures 4A, B) above both anticlines, an evidence supporting the hypothesis of ongoing folding after thrust imbrication; these relationships outline a geometry that is indicative of piggy-back, i.e. hinterland-to-foreland directed thrust propagation. The onset of thrusting leading to the emplacement of Lagonegro II onto Lagonegro I Unit cannot be directly dated, as the youngest sediments on top of the lower nappe in the study area are Lower Cretaceous in age and thrusting is certainly much younger. Deformation probably initiated in Langhian time, as indicated by the syn-tectonic sedimentation of the Langhian to Tortonian Gorgoglione flysch.

iii To the west of Marsico Nuovo the thrust contact between the Campania-Lucania Carbonate Platform Unit and the Lagonegro Units, is well exposed. The Lagonegro imbricates are structurally overlain to the west by carbonates of the Monti della Maddalena Thrust (MMT). In the western edge of the Agri Valley the fault surface gently dips to the southwest. The poor exposure of the thrust contact in the study area does not allow to unequivocally infer the geometric and chronological relationships between the deformation of Lagonegro Unit rocks and the emplacement of the MMT; Mazzoli et al. (2001) claim that the emplacement of the MMT occurred after substantial folding of the Lagonegro nappe. However, more recent studies (Bucci et al., 2019) document the occurrence of an important shear zone at the base of the main thrust of the Campania-Lucania Carbonate Platform Unit onto the Lagonegro Units; this shear zone is characterized by the occurrence of strongly asymmetric folds, a well developed cleavage, S–C fabrics and duplex structures. These findings may be better explained considering a coeval emplacement of the MMT and substantial deformation of the Lagonegro nappe, suggesting a piggy-back thrust propagation (which is, in turn, consistent with the antiformal folding of the thrust surface that separates the Lagonegro II from the Lagonegro I Units at the northern termination of Mt. Lama, described above). Alternatively, undulations in the strike of the MMT recognized and documented by Ferranti et al. (2005) on the north-western side of High Agri Valley, suggest that this fault (i.e. the MMT) might have been refolded together with its footwall and hanging-wall, implying ongoing folding after the main thrusting episode responsible for the emplacement of the Campania-Lucania Carbonate Platform Unit onto the Lagonegro Units.

iv Three major, roughly north–south-trending, faulted antiforms are exposed in the study area. From west to east these are the Monte Cugnone, the Monte Lama – Monte Calvelluzzo and the Monte Volturino structures. These antiforms affect the Mesozoic succession of the Lagonegro I Unit (LI). The Monte Cugnone Fold is a broad anticline with north-westerly structural plunge beneath the Marsico Nuovo Thrust. The Monte Cugnone anticline is cored by cherty limestone exposed in the Monte Cugnone quarry (Figure 5B). The Monte Lama structure consists of a large box fold, with a nearly vertical western limb and a steep to overturned eastern limb (Figure 4A). East of it, the Monte Volturino structure also consists of a large antiform, showing a box fold geometry with a flat top. The western limb of this structure is downfaulted to the west, whereas the overturned eastern limb links with an overturned, east-verging syncline, as documented by several measurements of overturned beds at 'La Torre' site, SSE of Monte Volturino (see Main Map and Figure 3E, lower left corner). The geometry of these anticlines suggests that they grew as buckles, due to décollement folding. The thick Calcari con Selce formation is the main unit of the folded multilayer that controlled the size, geometry and wavelength of the anticlines. The regular alternation of shales, marls and calcarenites of the Sorgente dell'Acero formation, at the base of the succession, acted as détachment matrix and experienced strong internal deformation, as documented by tight folds associated with well developed axial planar cleavage in the core of the Mt. Lama – Mt. Calvelluzzo anticline (Figures 3C, 5C). The Sorgente dell'Acero formation crops out at the base of the uplifted footwall blocks of the main sub-vertical oblique faults bounding the NE margin of the high Agri Valley Basin (Figures 3C,D and Figure 4C, D). Due to its stratigraphic position, the Sorgente dell'Acero formation provides an important constraint to the thickness of the overlying Calcari con Selce, and to the geometry of map-scale folds. Construction of the cross sections benefitted of the identification of several outcrops of the Sorgente dell'Acero formation, that is recognized and mapped in this contribution for the first time (Figure 3C, D).

v The Monte Lama – Monte Calvelluzzo anticline is bounded on its eastern and western sides by (either emergent or blind) thrusts and back-thrusts, respectively, and shows a double vergence of associated fold structures (see Main Map). Eastward, a gently-dipping thrust fault at the base of the eastern slope of the Mt. Lama ridge, carries the overturned limb of the Mt. Calvelluzzo anticline (consisting of Calcari con Selce) onto upright Flysch Galestrino in the footwall (see Main Map). Westward, a steep reverse fault cuts the base of the western slope of the Mt. Lama ridge (see Main Map and Figures 4C, 5D). Minor reverse fault surfaces, associated with the backthrust, postdate the formation of the fold. To the north and south, the thrust and back-thrust progressively lose displacement and die, along strike to be replaced by an anticline-syncline pair at both lateral tips (see Main Map and Figure 3C). This feature is characteristic of thrust propagation across already folded rocks (Coward & Kim, 1981; Fisher et al., 1992).

vi In the Monte Volturino area (Figures 3E, 4E) major attention was paid to ascertain the relationships between 'klippen' of carbonate platform rocks of the Campania-Lucania Carbonate Platform Unit and their substratum, represented by an assemblage of Lagonegro I and II Units, and by additional exotic material. These scattered outcrops of platform carbonates are generally interpreted as thrust remnants, or klippen (ISPRA, in press-a; in press-b; Servizio Geologico d'Italia, 1969). However, the results of recent investigations (Novellino et al., 2015) document that the basal tectonic contact of the klippe cuts and truncates folds, thrusts and related structures in its footwall. The low-angle tectonic contact at the base of the klippe cuts down-section in the footwall, and exhibits distinct extensional features (see Main Map and cross sections). We consider this as evidence for a post-thrusting emplacement of the 'klippen'. We further hypothesize that the 'klippen' were emplaced on their substratum along low-angle normal faults. Kinematic indicators are poorly preserved in the footwall of the 'klippen'. At Mt. Volturino, a thin layer of Oligocene terrigenous sediments, pertaining to the Argilliti del Torrente Serrapotamo formation, crops out along an east-dipping low-angle tectonic contact that carries Campania-Lucania Carbonate Platform sediments on top of rocks of the Lagonegro II unit (Figure 3E). Slivers of these Oligocene sediments are associated with chaotic terrains, consisting of a highly disrupted tectonic level where the original sedimentary features and rock fabrics are obliterated. For an exhaustive description of additional features that further support the emplacement of the Campania-Lucania Carbonate Platform 'klippen' as due to activation of low-angle normal faults the reader is referred to Bucci et al. (2014).

vii In the Marsico Vetere area (Figure 3F) different well exposed fault systems, with extensional and transtensional kinematics and their crosscutting relationships, were investigated. The oldest fault population mapped in the Marsico Vetere area consists of a system of NNW-SSE trending, eastward dipping, low-angle (dip values ranging from 20° to 40°) normal faults. These low-angle normal faults affect the carbonate rocks of the Campania-Lucania Carbonate Platform Unit, and separate the Triassic dolostones (in the footwall) from the Jurassic limestones (in the hanging-wall) (Figure 5E). Two younger fault systems, respectively trending NE-SW and NW-SE, cut across and clearly offset these low-angle normal fault. Several exposures of NE-SW trending normal faults are located between Mt. Volturino and Mt. di Viggiano, and define a morphostructural depression named Sorgente Copone Graben (SCG) (Figure 4F). Inside the graben grey shales and mixed calcareous siliciclastic turbidites belonging to the Torrente Cavolo formation extensively crop out. In the present map, the SCG represents the only outcropping area of the exotic rocks of Ligurian Unit. Two main normal faults, the Pietra Liscia Fault (PLF) and the Marsico Vetere Fault (MVF), bound to the north-west and to the south-east, the SCG for a length of about 4 km. Southward both faults terminate against the lowermost strand of the East Val d'Agri Fault System (EAFS, according to Bucci et al., 2013) and are covered by the quaternary deposits filling the High Agri Valley. Northwards these structures terminate against, being truncated by, the uppermost strand of the EAFS. Both PLF and MVF have been dissected in several segments by quaternary NW-SE oblique-to-strike slip faults with left-lateral kinematics (see Main Map and Figures 3F, 4F, 5F). The Fault system strongly affects roughly stratified talus breccias of early to middle Pleistocene age (Di Niro et al., 1992), which are tectonically juxtaposed to the Mesozoic bedrock. Along the same NW-SE trend, the traces of basin-ward-dipping faults are locally documented by metre and sub-metre scale steps in the slope profile, suggesting active deformation in very recent times.

6. Conclusions

The geological map (main map) presented in this study integrates stratigraphic and structural information obtained through field surveys and rock sampling, coupled with an exhaustive review of the scientific literature that covers the area.

Our work describes a number of significant map-scale structures, which can be related to well-constrained tectonic episodes including: i) the pre-orogenic deposition, onto the attenuated, rifted margin of the Adria plate, of sedimentary succession in both basinal and carbonate platform environments; ii) the syn-orogenic evolution of the Apennine fold-and-thrust belt; and iii) the post-orogenic modification of the contractional architecture of this part of the southern Apennine orogeny by means of sequentially younger strike-slip, transtensional and extensional tectonics.

If compared to the available literature, the new geological map represents a significant improvement upon earlier mapping because: i) it presents an updated stratigraphy of the Lagonegro succession, with description of a new lithostratigraphic unit, the Sorgente dell'Acero formation, that was recognized and is mapped for the first time in this contribution in three key areas of the High Agri Valley; ii) it better constrains the thickness of the Calcari con Selce formation, embedded between the informal Sorgente dell'Acero and Transitional interval formations; iii) it documents a previously unreported pre-orogenic normal fault, whose syn-sedimentary activity is ascribed to the Jurassic. The map pattern reveals the structural and geometric control of this normal fault on nucleation and growth of the subsequent Mt. Lama – Mt. Calvelluzzo pop-up structure; iv) it provides unprecedent, spatially distributed information on the distribution and geometry of unrooted low angle normal faults, affecting the rocks of the Lagonegro II and the Campania-Lucania Carbonate Platform Units, which modify the inherited thrust related fabrics and architecture; v) it documents the effects of NE trending normal faults, which post-date the low-angle normal faults and, in turn, pre-date the activity of NW trending oblique-slip and normal faults, that are the main responsible for the tectono-stratigraphic evolution and the geometry of the Val d'Agri post-orogenic trough/graben.

Our findings provide new, original constraints for elucidating the complex stratigraphic and structural framework of this part of the southern Apennines of Italy.

Software

We used Adobe® Illustrator® (http://www.adobe.com/products/illustrator/) to assemble the final map and the cross sections for publication and graphical editing, and to prepare the Adobe© PDF file of the map.

7. Cartographic information

Topographic Map of Italy, 1:25.000 scale, I.G.M. Serie 25. Autorization n. 4, 2011-10-28. The topographic base map results from the patch of 4 individual section, and namely: i) F. No 489 sez. II – LAURENZANA; ii) F. No 489 sez. III – MARSICO NUOVO; iii) F. No 505 sez. I – VIGGIANO; iv) F. No 505 sez. IV – TRAMUTOLA. Kilometric coordinates in ED 50 DATUM – Zone 33 N. Main contour interval is 25 m.

The map is published at the 1:25,000 scale, that provides a good representation of the geological structures cropping out in the study area. However, it should not be used to determine the exact geological and tectonic conditions of specific, individual sites or locations. For the purpose, site-specific investigations, carried out with greater detail, are deemed necessary.

Acknowledgements

The geological survey used in this work was prepared by Francesco Bucci during his PhD, under the co-supervision of Giacomo Prosser (University of Basilicata), whose help is acknowledged. We are grateful to Francesco Muto, Simone Fabbi and Heike Apps for their positive and constructive comments.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

Work partly supported by Internal Research Projects, Italian Institute for Geo-hydrological Protection, National Research Council (IRPI-CNR), grant to Francesco Bucci (FB).

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